Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical and Industrial Engineering

Design, Analysis and Optimization of Photovoltaic Thermal Collector and Storages Tank

A thesis Submitted to Addis Ababa Institute of Technology, Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in School Mechanical and Industrial Engineering under Thermal Engineering Stream

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BY KIFLE FISEHA

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Declaration

I, the undersigned, declared that this MSc thesis is my original work, has not been presented for fulfillment of a degree in this or any other Universities, and all sources and materials used for the thesis work is acknowledged.

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This Thesis work has been submitted for examination with my approval as a University Advisor.

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Kifle Fisaha

Contents

Abbreviation

GHG	Green House Gas
Co_2	Carbon di oxide
MW	Mega Watt
PV	Photovoltaic
PV/T	Photovoltaic/ Thermal
FPC	Flat Plate Collector
BIPV/T.	Building Integrated Photovoltaic/Thermal System
R	Radius of the Earth
Gsc	Solar constant
φ	Latitude

δ	Declination angle
β	Slope
γ	Surface Azimuth Angle
ω	Hour Angle
θ	Angle of Incidence
θ_z	Zenith Angle
α_s	Solar Azimuth Angle
G	Solar irradiance,
H	Daily insolation
I	Hourly insolation
Lst	Standard meridian for the local time zone,
Lloc	Longitude of the location
a-Si	Amorphous silicon
CdS	Cadmium sulfide
Ga As	Gallium arsenide
FPV/T	Flat Plate Photovoltaic/ Thermal
TPT	Tdlar- polys tertedlar
EVA	Ethylene–vinyl acetate
LCC	Life Cycle Cost
CPT	Cost Payback Time
EPBT	Energy Payback Time
GPBT	Greenhouse Payback Time
Io	Dark saturation current
e	Electronic charge
Tc	Cell absolute temperature
V	Voltage across the cell
K	Boltzmann's constant.
Isc	Short circuit current
V_{oc}	Open circuit voltage
P_{max}	Maximum power

V_{max}	Maximum voltage
$\eta_{max_{ref}}$	Maximum power point efficiency
T_{ref}	Reference temperature
μ	Temperature Coefficient
Qu	Useful energy
Ac	Collector area
τ	Transmittance of glazing cover,
α	Absorptance of the glazing cover
U_L	Overall thermal loss coefficient,
Ta	Ambient air temperatures
Tmp	Mean absorber plate temperatures.
Qe	Heat energy converted electrical energy
FR	Heat removal factor
Di	Internal diameter of the tube
De	External diameter of the tube
F'	F in efficiency factor
F	Fin efficiency
Cb	Bond conductance
C	Consumption
hpd	Hour per day
CPD	Consumption per day
TFA	The total floor area
N	Number of occupants,
T_b	Atmospheric transmittance
A	Altitude of the observer in kilometers
Ho	Extraterrestrial radiation for that day
K_T	Daily clearness index
I	Hourly radiation
k_T	Hourly clearness index

Io	Hourly extraterrestrial radiation
$\overline{Hc}$	Average clear -sky daily radiation horizontal surface.
a' and b'	Empirical formulas
r_t	Ratio of hourly total to daily total radiation
Rd	Ratio of diffuse on the tilted surface to that on the horizontal

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CHAPTER ONE

1. INTRODUCTION

1.1 Research Background

Energy is one of the basic needs in the life of humans. Likelihood, it is possible to conclude that, there is no any moment without this significant factor and (because of this) the rapidly increasing world population growth gives rise to a greatly increased demand for energy. Do(due) to this reason extensive fossil fuel consumption by human activities has led to serious atmospheric and environmental problems. See fig 1.1. Consequently, global warming, greenhouse gas (GHG) emission, climate change, ozone layer depletion and acid rain terminologies have started to appear. frequently in the literature growing global energy and needs concern for environmental fortification. To achieve this interested idea many governments and stockholders in the world have addressed ambitious goals by using new technologies to reduce their energy footprint and CO_2 emissions. [1]

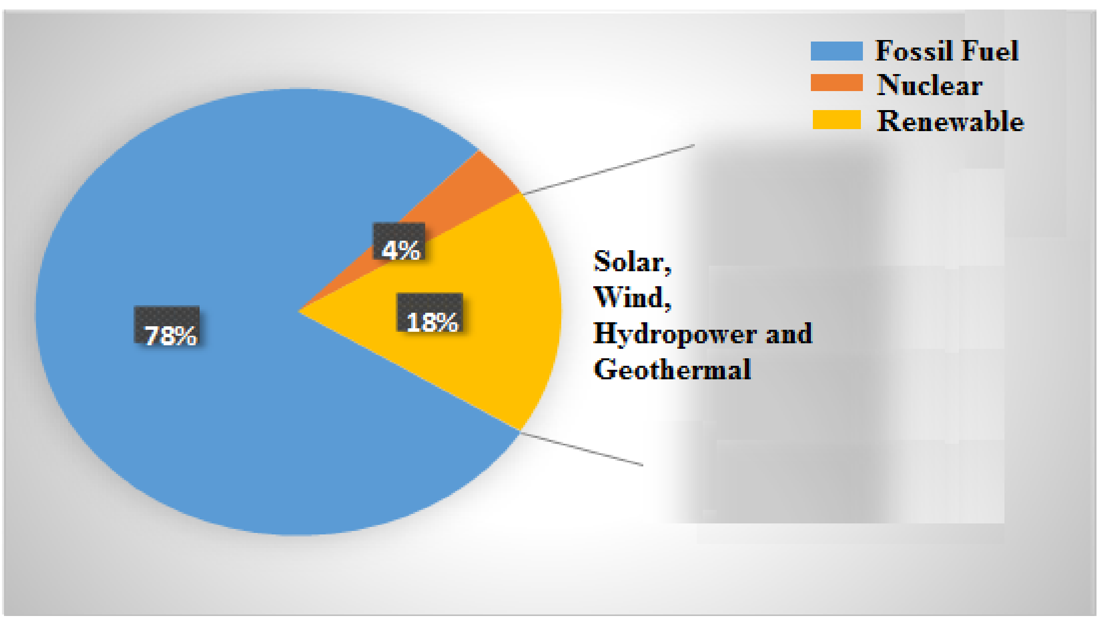

Figure 1.1. World Energy Consumption

In the context of the Ethiopian which has a very poor power supply penetration rate. Electricity is available for 21% of the population and only 17% of the households are connected to the central grid; even the above attention is restricted to major towns and cities the rest 80% rural population uses bio fuel like wood, animal product. This under standard energy usage style of the country has great impact on the industrialization development, degradation of the environment and heath problem especially mothers and children. To overcome this series issue, the Ethiopian government has been started a lot of mega project here and there. More attractively they declare the energy policy free from carbon emission up to 2025.By using the huge natural source of alternative energy like hydro power, wind, geothermal and solar. [2]

In the outlook of this energy policy, the opportunity of seriatim solar power using the energy from the sun is receiving considerable attention in recent years. From environmental point view solar energy is clean and most inexhaustible of all known energy sources and also reducing ultraviolet rays are very interesting in reducing the global warming. From energy point of view especially in the Ethiopian context solar energy is inspiring since there is ten-month sunshine session and it can contribute solution for the unbalanced energy supply relative to high demand at this time at national level.

Frankly speaking, solar energy has playing an essential role in the energy supply. And diverse uses of solar energy in rapports of solar thermal accumulators and PV devices have been embryonic on the market for years and still have great chance for growth, which should be driven by continuous practical advances and increased concerns regarding energy saving and environmental protection. So far Ethiopian has just start to use from this technology like PV electricity and hot water for domestic level, and also the central governmental has plan to build 300 MW Solar PV electricity systems at national level. [4]

To do this technology more useful in the concept of our country more research is need on hybridization photovoltaic/thermal (or simply PV/T) collectors are devices that simultaneously converts solar energy in to electricity and heat. A PV-Thermal (PVT) collector is a module in which the PV is not only producing electricity but also serves as a thermal absorber. Since the demand for solar heat and solar electricity are often integrated, it seems a logical idea to develop a device that can comply with both demands. Research and development on this topic has been promising during the last three decades. Some reviews on PVT collectors have recently been published by Tyagi, V.V. Kaushik, and S.C [4,5].

1.2 Problem Statement

As we have seen the energy profile our country Ethiopia and the energy policy in the research background, Ethiopia has huge capacity of solar energy because of high sunshine time through the year, almost 365 days per year. But there is no enough power supply and distribution throughout the country especially rural area. And consequentially this problem leads to inadequate institutions services like off-grid rural residential, health centers, elementary school, military camp and lounge which need electricity and hot water. Of course in recent time there is some activities in photovoltaic solar electric cell which has the inherent character decreasing efficiency when ambient temperature increases. To simplify this problem, we have to use the optimization design of photovoltaic thermal (PVT) including simultaneously cooling-heating system to maintain the maximum efficiency of the system and to use the wasted energy from this as source of heating water.

1.3 Research question

In overall, the investigation of the research has been directed by addressing and answering the following research questions:

1 Is solar energy for selected site-and is PV/T- hybrid configuration can produce an optimal combination for rural electrification?

2 Is there any impact on the environmental, social and political regarding to this activity?

3 Is hybrid system economic feasible for the rural electrification**?**

1.4 Objectives

The general objective of this research is analyzing and designing of a photovoltaic solar thermal system for off-grid consumers like rural residential, health center, elementary school, military camp and lounges which need electrical energy and hot water simultaneously. Also modeling and simulation of the system is expressed using commercial software**.**

The specific objectives of this thesis are,

i. Optimized sizing of the photovoltaic-thermal collector system based the total energy demand Analyzing and estimating the daily, hourly solar radiation intensity and temperature variation of a photovoltaic-thermal collector system.

ii. Designing a photovoltaic solar thermal system to meet the required electricity, outlet temperature of the hot water.

iii. Designing the heat storage mechanism and selecting appropriate material.

iv. Modeling the system and simulation using software like Matlab and ANSYS.

v. Making technical and economic feasibility study of the hybrid system-relative PV alone and other alternative energy like wind, small-hydropower

1.5 Scope of the Study

The scope of this study is to evaluate the technical and economic feasibility of an off-grid PV/T hybrid energy system to supply the rural community particularly elementary school staff and military camp faraway from national grid in Ethiopia. This study shall gather and investigate applicable facts and evidence to survey and select the most suitable systems configuration, recommend necessary action, necessary measures that configure a system to accommodate the current and near future electrical energy demand.

1.6 Delimitations

This research gives the inspiration in synergistic benefit of solar PV/T thermal plant configuration based flat plat collector with water cooling system. Since flat plate collector (FPC) is the heart of any solar energy collection system designed for operation in the low temperature range (less than 60^{0}C) or in the medium temperature range with the objectives of increasing and improving net clean energy use in for off-grid health centers, decreasing the overall energy cost since the solar energy is free once installed as soon as the efficiency of the plant, reducing the cost of electricity production without facing problems the environment (atmosphere) from carbon emission. But in this optimized PV/T we are not lack to get the previous works which has been native scholars.

CHAPTERTWO

2. LITERATURE REVIEW

A number of scholars have been conducted in hybrid Photovoltaic thermal off-grid power generation. Many academic societies and researchers used poles-apart know-how option and approach to assess the various configurations on this Technology, so far many findings and has been published some of the thesis paper are reviewed and evaluated in the following paragraph.
Xingxing Zhang (2014) existing solar photovoltaic/thermal (PV/T) technologies by incorporating an innovative analysis. he did the comparative study in coated aluminum-alloy (Al-alloy) sheet versus the conventional base board for the PV cells. The main objective of the researcher was to extract un excesses heat from the PV module and he investigated successfully through full range of specialized simulation models and developed to predict the system performance with reasonable accuracy and tested the system through experimental methods. According to Zhang conclusion the PV increases 10% efficiency in its electrical system. The test results indicated that the system performed better than conventional solar/air energy systems. But what not accepted in Zhang job; the system is so complex because he used many working fluid and refrigerants which is very difficult to apply in Ethiopian rural areas since most the people is not educated and illiterate. [6]
Ricardo Jorge and Silva Pereira (2015) presents a numerical and experimental analysis of the thermal and electrical performance of a building integrated photovoltaic/thermal system (BIPV/T). They used of phase change material for stabilize the temperature difference between indoors and outdoors and a rapid stabilization of the PV modules' temperature. Also they have calculated and developed of the heat and mass transfer phenomena, as well as a model of a photovoltaic module, which were implemented in Matlab. Experimental tests were performed to analyze the thermal performance of the system and the validation of the numerical model. To improve overall system efficiency, an optimization process with the method of genetic algorithms was applied. From their study, they concluded that the system can achieve a maximum total efficiency of 64% with winter configuration and 32% with summer configuration.

2.1 Fundamental of Solar Energy

On the investigation of research and study's relative solar energy there is some Astronomical basic data about the sun and the relation between earth and sun, some of these are described below.

2.1.1 Sun

The sun is a compass of powerfully warm gassy substance with approximately diameter of (1.39×10^{9}m) and is, on the average distance (1.5×10^{11}m) from the earth. It has an actual blackbody temperature of (5777K). The temperature in the central interior regions is variously estimated at (8×10^{6} to 40×10^{6} K) and the density is estimated to be about 100 times that of water. A progression of Radiative and convective processes occurs with successive emission, absorption and re radiation; the radiation in the sun's core is in the x-ray and gamma-ray parts of the spectrum, with the wavelengths of the radiation increasing as the temperature drops at larger radial distances [7]. It is estimated that 90% of the energy is generated in the region of 0 to 0.23 R (where R is the radius of the sun), which contains 40% of the mass of the sun. At a distance 0.7R from the center, the temperature has dropped to about 130,000 K and the density has dropped to 70 kg/m3; here convection processes begin to become important, and the zone from 0.7 to 1.0 R is known as the convective zone. Within this zone the temperature drops to about 5000 K and the density to about 10^{-5}kg/m^{3} ref [7].

The sun's surface appears to be poised of granules (irregular convection cells), with dimensions from 1000 to 3000 km and with cell lifetime of a few minutes. Other features of the solar surface are small dark areas called pores, which are of the same order of magnitude as the convective cells, and larger dark areas called sunspots, which vary in size. The outer layer of the convective zone is called the photosphere. [7].

2.1.2 Solar Constant

The photosphere is the source of most solar radiation. Outside of that this layer referred to as the chromosphere, with a depth of about 10,000 km. This is a gaseous layer with temperatures somewhat higher than that of the photosphere but with lower density. [3 Thomas]. The energy emitted by the sun and its multi-dimensional correlation to the earth result in a nearly fixed intensity of solar radiation outside of the earth's atmosphere. The solar constant Gsc is the energy from the sun per unit time received on a unit area of surface perpendicular to the direction of propagation of the radiation at mean earth-sun distance outside the atmosphere. Of course this varies depending on day of the year as Earth rotaries along Sun. look the figure below. Since the distance between the sun and the earth varies every day the intensity of the extraterrestrial solar radiation also varies.

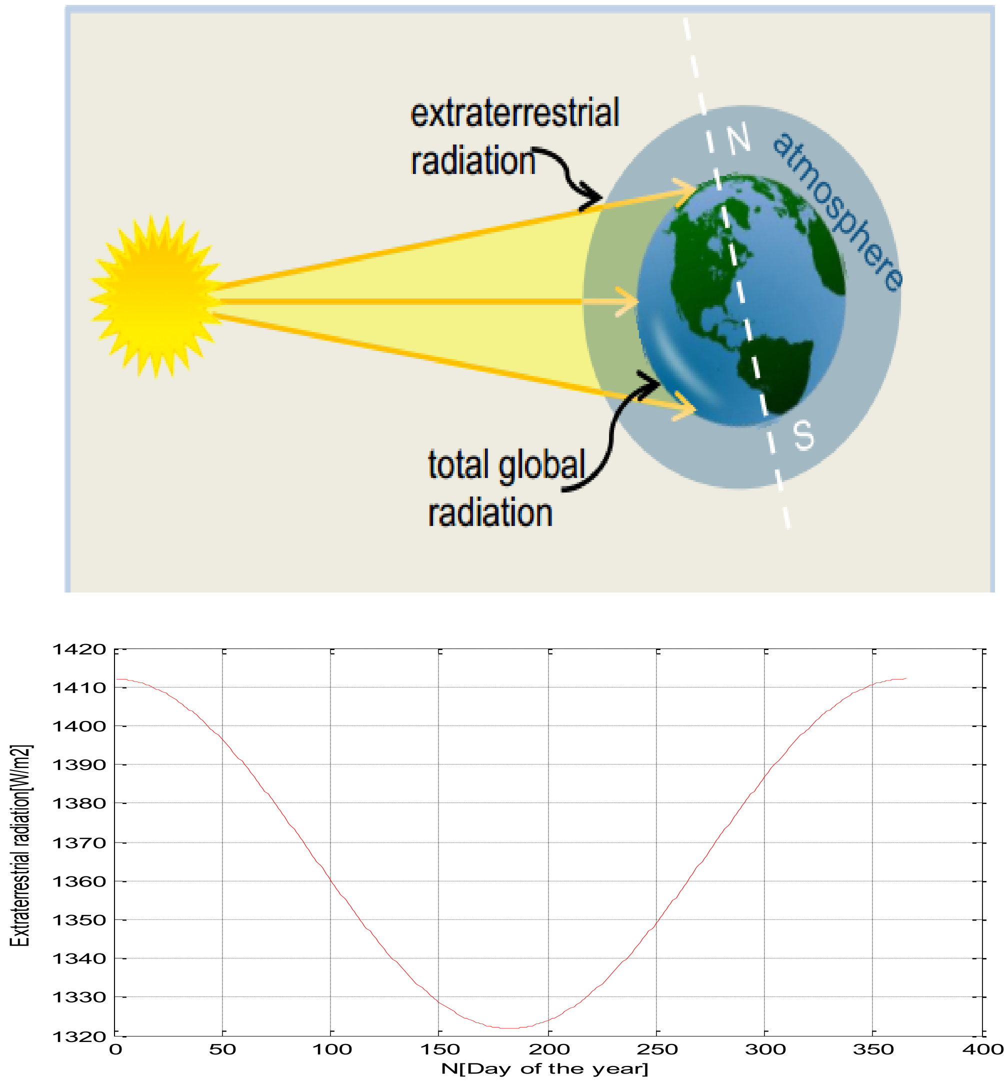

Figure 2.1: Intensity of the Extraterrestrial Solar Radiation

Pioneering studies were done by C. G. Abbot and his colleagues at the Smithsonian Institution. These studies and later measurements from rockets were summarized by Johnson (1954); Abbot's value of the solar constant of 1322 W/m^2 was revised upward by Johnson to 1395 W/m^2.

Data from Nimbus and Mariner satellites have also been included in the analysis, and as of 1978, Froehlich recommends a new value of the solar constant Gsc of 1373 W/m^2, with a probable error of 1 to 2%. This was 1.5% higher than the earlier value and 1.2% higher than the best available determination of the solar constant by integration of spectral measurements. [7]

2.1.3 Solar Radiation Geometry

For determine and assessing the amount of solar energy for any application the primary task is estimating the actual radiation in selected area. To do this the geometric relationships between plane of any particular orientation relative to the earth at any time (whether that plane is fixed or moving relative to the earth) and the incoming beam solar radiation, that is, the position of the sun relative to that plane is the basic concept. Some of the angles are indicated in Figure below The angles and a set of consistent sign conventions are as follows:

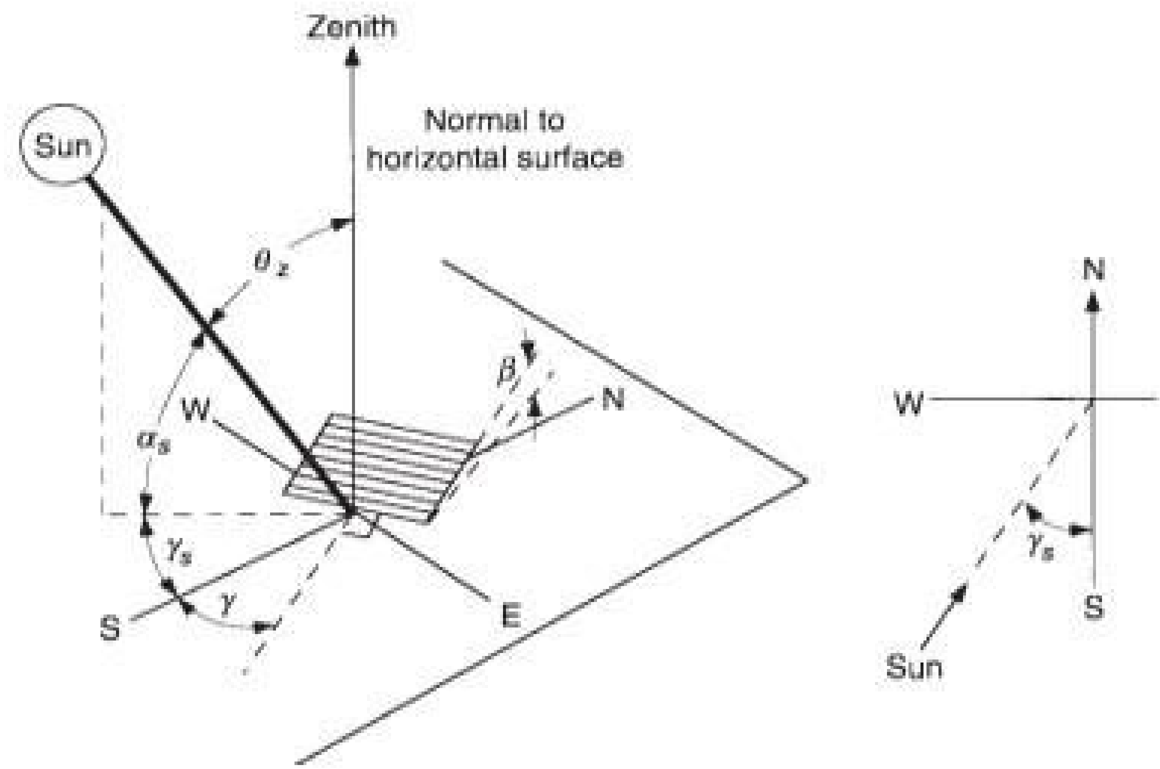

Figure 2.2:The Angles and a Set of Consistent Sign Conventions are as Follows

- **Latitude (φ):** The angular location north or south of the equator, north positive; $(-90^0 \leq \varphi \leq 90^0)$
- **Declination (δ)**: The angular position of the sun at solar noon (i.e., when the sun is on the local Meridian) with respect to the plane of the equator, north positive; $(-23.45^0 \leq \delta \leq 23.45^0)$**.**

$$\delta = 23.5 \sin \frac{(360 * (284 + n))}{365} ---------- Eq(2.1)$$

(Where n is day of the year starting from January 1….365)

- **Slope (β):** The angle between the plane of the surface in question and the horizontal; (0∘≤β≤180∘.β>90°) means that the surface has a downward-facing component.)
- **Surface azimuth angle (γ)*:*** The deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, with zero due south, east negative, and west positive; ($-180^0 \leq \gamma \leq 180^0$)
- **Hour angle (ω):** The angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15^0per hour; morning negative, afternoon positive.

$$\omega = (ST - 12) * 15° - - - - - - - - - - - - - - Eq(2.2)$$

- **Angle of incidence (θ):** The angle between the beam radiation on a surfaces and the normal to that surface. Additional angles are defined that describe the position of the sun in the sky this angle may be expressed as function of other angle as follow.

$$\text{Cos } \theta = \sin \delta \sin \varphi \cos \beta - \sin \delta \cos \varphi \sin \beta \cos \gamma + \cos \delta \cos \varphi \cos \beta \cos \omega$$
$$+ \cos\delta \sin\varphi \sin\beta \cos\gamma \cos\omega + \cos\delta \sin\beta \sin\gamma \sin\omega - - (2.3)$$

- **Zenith angle (θz)*:*** The angle between the vertical and the line to the sun, that is, the angle of incidence of beam radiation on a horizontal surface.
- **Solar Altitude Angle (αs);** The angle between the horizontal and the line to the sun, that is, the complement of the zenith angle**.**

$$\cos\theta_z = \cos\varphi\cos\delta\cos\omega + \sin\varphi\sin\delta - - - - - - - - -(2.4)$$

- **Solar azimuth angle (γs)**: The angular displacement from south of the projection of beam radiation on the horizontal plane, shown in Figure Displacements east of south are negative and west of south are positive.

Table 2-1: Sign convention of the Earth-Sun Angles and Observer – Sun Angles

Title	Zero	Range	Positive Direction
Latitude ($\boldsymbol{\varphi}$)	Equator	$\pm 90°$	Northern hemisphere
Declination angle ($\boldsymbol{\delta}$)	Equinox	$\pm 23.45°$	Summer
Slope ($\boldsymbol{\beta}$)	Horizontal	$[0 - 90]°$	Upward
Surface Azimuth Angle ($\boldsymbol{\gamma}$)	South	$\pm 180°$	South west
Hour Angle ($\boldsymbol{\omega}$)	Noon	$\pm 180°$	Afternoon
Angle of Incidence ($\boldsymbol{\theta}$)	Surface norm	$[0 - 90]°$	-
Zenith Angle ($\boldsymbol{\theta_z}$)	Vertical	$[0 - 90]°$	Toward horizontal
Solar Azimuth Angle ($\boldsymbol{\alpha_s}$)	South	$\pm 180°$	Clockwise

2.1.4 Solar Radiation Components

Beam Radiation: Is a solar radiation which is the radiated energy from the sun devoid of having been scattered by the atmosphere. This is simply called direct solar radiation.

Diffuse Radiation: The solar radiation which gained after its direction has been changed by handful by the atmosphere. The definition used here will differentiate the diffuse solar radiation from infrared radiation emitted by the atmosphere.

Global (total) Solar Radiation: Is amount of the beam and the diffuse solar radiation on a surface. This is the most common measurements of solar radiation which may be measured as total radiation on horizontal surface or on inclined surface.

Irradiance (W/m^2): Is the rate at which radiant energy is incident on a surface per unit area of surface. The symbol G is used for solar irradiance, with appropriate subscripts for beam, diffuse, or spectral radiation**.**

Irradiation or Radiant Exposure (J/m^2): Is the incident energy per unit area on a surface, found by integration of irradiance over a specified time, usually an hour or a day. [7]

Insolation: Is a term applying specifically to solar energy irradiation. The symbol **H** is used for insolation for a day. The symbol **I** is used for insolation for an hour (or other period if specified). The symbols **H** and **I** can represent beam, diffuse, or total and can be on surfaces of any orientation**.**

Solar Time: Is time based on the apparent angular motion of the sun across the sky with solar noon the time the sun crosses the meridian of the observer. Solar time is the time used in all of the sun-angle relationships; it does not coincide with local clock time. It is necessary to convert standard time to solar time by applying two corrections. First, there is a constant correction for the difference in longitude between the observer's meridian (longitude) and the meridian on which the local standard time is based. The sun takes 4 min to transverse 10 of longitude. The second correction is from the equation of time, which takes into account the perturbations in the earth's rate of rotation which affect the time the sun crosses the observer's meridian. The difference in minutes between solar time and standard time is:

$$Solar\ Time = 4(L_{st} - L_{loc}) + ------------ (2.5)$$

Where: Lst is the standard meridian for the local time zone, Lloc is the longitude of the location in question, and longitudes are in degrees west, that is, $0^0 < L < 360^0$

$$E=229.2(0.000075+0.001868\cos B-0.032077\sin B-0.014615\cos 2B-0.04089\sin 2B)$$

Where: B= (n−1) $\frac{360}{365}$ and n day of the year [7]

2.2 Solar Energy Collection Technologies

As try to mention above in the research back ground solar technology are good solution in the substituting of the traditional energy use and this has been started before 40 years ago. From day to day the technology is spread out to the world population and getting acceptance in mullt-dimensional factors.

2.2.1 Solar Thermal Collectors

Solar thermal collectors gather heat energy which is then transferred to the working fluid in the heating or plumbing systems. Solar thermal panels can usually be classified as flat plate or evacuated tube design. The flat plate designs are easier to produce and harder to damage than evacuated tubes. A typical flat plate thermal panel consists of an enclosed insulated metal box with a dark-color absorber plate and fluid-based piping series of tubes connected to the absorber plate, so the heat will transfer from the plate, to the tube and into the fluid.

This solar energy technology is commonly used in the heating of a home or building through architectural design. In Ethiopian context since heating home is not that much necessary, it is better use producing hot water which accounts for approximately 25% of the total energy used in a typical single-family home and can lead to savings of 85% on the utility bills over the costs of bio fuel water heating. [8]

2.2.2 Photovoltaic Cells

Photovoltaic cell which is the modern solar technology is semiconductor devices that convert part of the incident solar radiation directly into electrical energy. A brief history of photovoltaic is presented by Wolf (1981). There are many variations on cell material, design, and methods of manufacture. Amorphous or polycrystalline silicon (Si), cadmium sulfide (CdS), gallium arsenide (GaAs), and other semiconductors are used for cells. Solar cell technology is evolving rapidly, in developing new and more efficient cells and in reducing costs of manufacture. Modules are available with many cells connected in series and parallel to provide convenient currents and voltages. Cell modules can be purchased on the market that are over 15% efficient and have design lifetimes of over 20 years. Experimental single crystalline silicon cells have been produced with efficiencies of 25% and cells with multiple junctions (i.e., two or more layers of materials with varying spectral response) have been constructed that have efficiencies of more than 30%. [9]

2.2.3 Photovoltaic/Thermal Collectors

This is the updated modern technology in the evolution of solar engineering, which get emphasis in this research. Hybrid photovoltaic/ (or simply PV/T) collectors are devices that simultaneously converts solar energy in to electricity and heat. They deliver an effective and appropriate means of obtaining electric power and thermal energy within the same system, maximizing on their total energy output. M. Boubekri. T. Bergene et al. proposed one model for the performance of hybrid PV/T, based on the energy transfer analysis. B Sandnes et al. developed an analytical model for PV/T collector by the modification of the Hottel and Willier model for the flat plate collectors.

H.A. Zondag et al. developed four numerical models to determine the performances of the hybrid collector. The model can give results for the horary analysis of performance and include the instantaneous efficiency thermal and electrical. [10]

Y. Tripanagnostopoulos et al. built and examined covered and uncovered PV/T collector with water and air as working fluid. J.S. It finds an efficiency thermal of about 58 % and one electric efficiency approximate equal to 11 %. [11]

Now a day's hybrid collectors PV/T solar systems technology is rapidly developing, Optimization of the structural/geometrical parameters e.g. dimensions and sizes, connections, shapes and establishing the favorable operating conditions such as fluid flow rates and pressures. Since almost more than half of the irradiance on a PV is absorbed as heat and then wasted off at the back panel, the fluid within the thermal panel helps to remove the heat from behind the photovoltaic cells. As photovoltaic cells heat up their efficiency decreases, for monocrystalline (c-Si) and polycrystalline (p c-Si) silicon solar cells, the efficiency decreases by about 0.45% for every degree rise in temperature. For amorphous silicon (a-Si) cells, the effect is less, with a decrease of about 0.25% per degree rise in temperature depending on the module design and Regular exposure to excessive heat can decrease the overall life expectancy of the cells panel [12].In the earlier works on theoretical analysis of PV/T system, Florschuetz extended the Hottel Whiller equation to model PV/T collectors and developed a linear relationship to predict the effect of cell operating temperature on the PV/T System efficiency. [13]

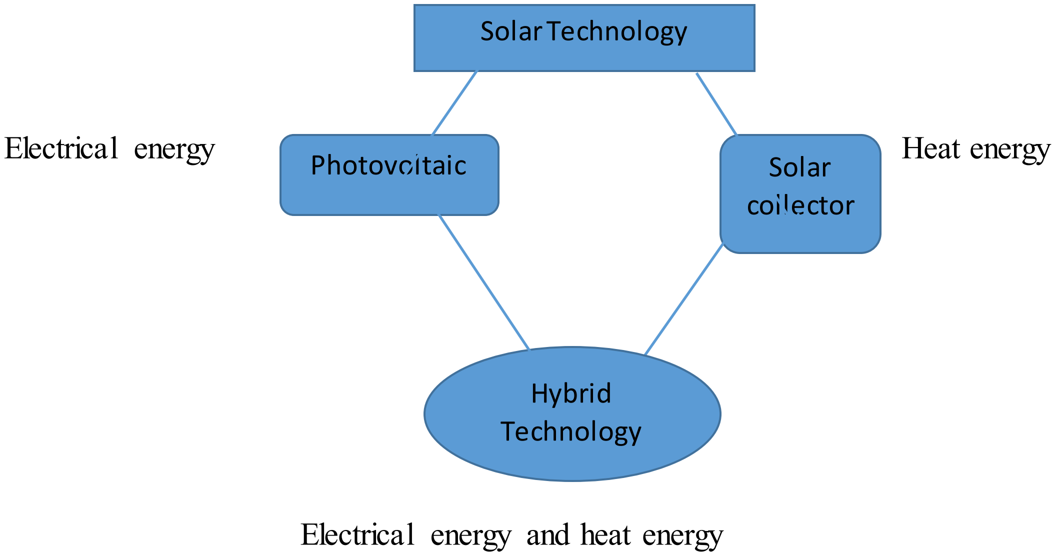

Figure 2.3: Evolution and Development of PV/T

Thus to intensification PV electrical productivity and create full use of solar radiation, it is required to remove the stored heat from the covered PV surface and collect the residual heat effectively. This is basic ideology and reason for developed PV/T technology and combines PV cells and heat extraction components in a single module. This subsequently allows cooling of the PV cells, increasing PV electrical efficiency and simultaneously supplying the extracted heat to the end users. Thus, hybrid solar collector can obtain an enhanced overall solar efficiency and provide an effective method for the utilization of solar energy.

In relation to this study, Jones and Underwood also derived an unsteady-state model expression for PV module temperature in terms of irradiance and ambient temperature. And also, Hendrie presents a hypothetical model of the PV / T using the procedures of conventional thermal plane collector based on the variation of collector's efficiency as a function of heat transfer fluid flux, pipe diameter, solar radiation intensity and active area of the parabolic trough concentrator.

2.3 Classification of Different Type PV/T

PV/T solar modules can be classified or categorized depending on many factors, to narrow up it can be classified into different groups. Most of the time the classification methods are based on working fluid for cooling of the system, and based on geometrical shape configuration of the system. From the point of view geometrical shape, PV/T can categorize as flat plat and concentrator. And from point of view cooling medium, there are currently three types of PV/T collector available, which are the devices developed using air, water and refrigerants. [14] This is summarized below.

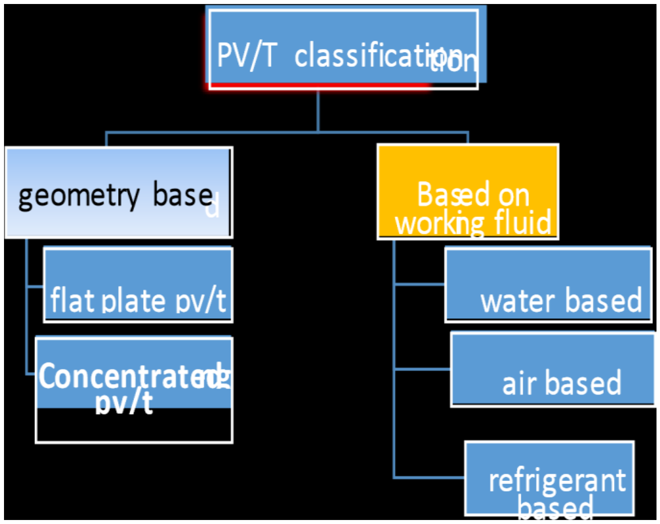

Figure 2.4: Classification of Different Type PV/T

2.3.1 Geometry Based Classification

i) Flat Plate PV/T Collectors

Flat plate PV/T collectors are just similar to the well-known flat plate thermal collectors. Which is made from PV panel that attached on the top of the metallic thermal absorber plate with the tubes, the FPV/T modules is may be glassing or not, that is depending the specific design cover as well as the insulation. The thermal production of FPVT would be likely to be less than that of a flat thermal collector, which is the objective of the system; meanwhile part of the obtainable solar irradiance is converted to electricity by the PV cells. Do to this, the electricity production should be expected to be higher than a standalone PV module. Since the PV cells are operating at a lower temperature [15].

ii) Concentrating PV/T Collectors

This is the second commonly categorized PV/T based on geometrical shape, concentrating PVT (CPVT) using low concentrating Compound Parabolic Concentrator (CPC) with mono-crystalline silicon cells. Coventry [3] developed the so called CHAPS (combined heat and power solar) PV/T collector. It involves a parabolic trough of concentration ratio of 37 times with mono-crystal in silicon cells and Brogren has incorporate PV/T string modules with low cost aluminum foil reflectors with a concentration ratio of 4.3 times.

Concentrating photovoltaic (CPV) systems can operate at higher temperatures than those of the flat plate collectors. Double-pass photovoltaic thermal solar collector with CPC and fins rejected heat from a CPV system leads to a CPV/thermal (CPV/T System, providing both electricity and heat at medium temperatures. The use of CPV/T in combination with concentrating reflectors has significant potential to increase the power production from a given solar cell area.

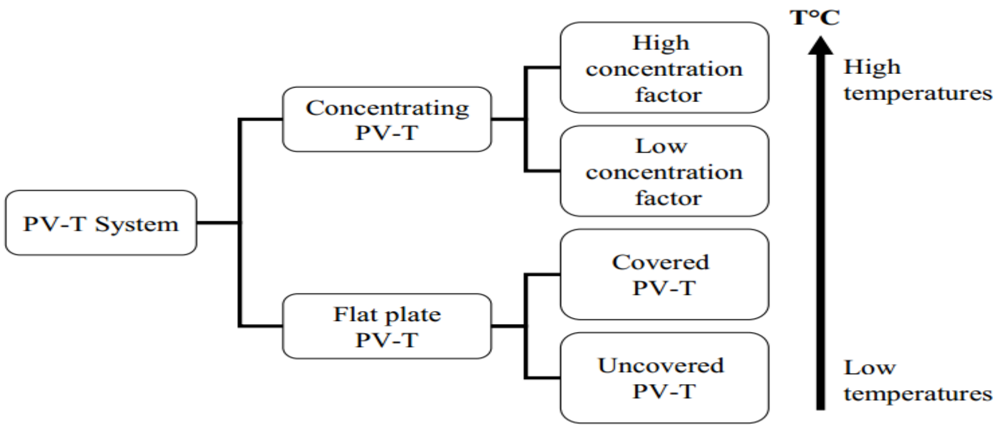

Figure 2.5: Profile of Temperature Distribution in Different Types of PV/T

2.3.2 Fluid Based PV/T

a) Water Based PV/T Collectors

In water based PV/T collector, the extra heat solar energy that passed within PV panel heats the water as it flows through tubes in the absorber plate. For this type of collector, the flow tubes are attached to below the absorber plate so the heat absorbed by the absorber plate is readily conducted to the liquid. [16]

b) Air Based PV/T Collectors

In air based PV/T collector, similar to the water based the extra heat solar energy that passed within PV panel heats the air as it flows through tubes in the absorber plate. But the flow direction of the air maybe different from the water, it may be in side tubes or through fin. This type of solar collector is becoming familiar in irrigation purpose for drying moisture of crop and commonly in air conditioning application.

Air and water both have been used as heat transfer fluids in practical PV/T solar collectors, yielding PVT/air and PVT/water heating systems respectively. PVT/water systems are more efficient than those of PVT/air systems due to the high thermo-physical properties of water as compared to air.

However, PVT/air systems are utilized in many practical applications due to low construction (minimal use of material) and operating cost among.

c) Refrigerant Based PV/T Collector

Research on refrigerant-based PV/T has been conducted in resent time. Kern and Russell initially wished-for a simple PV/T collector coupled with a heat pump system and studied the energy saving and economic benefits. This type of PV/T may apply on for low temperature conditions which allow the refrigerant to evaporate at a remarkably low temperature, e.g., 0-20^{o}C.As a result, the PV cells are cooled to a similar low temperature, which leads to a significant increase in the panel's heat and electrical efficiencies.

2.4 System and Principal Component of Water Based PV/T Technology

In this research more attention given for water based PV/T to achieve the objective according the stated problem. So now we have to investigate more on component of the water cooling. The detail analysis will be done in next two chapters. In this portion we try to see the system description and main principal component. The water based hybrid PV/T collector consists of a glass cover, a photovoltaic panel, which is made of polycrystalline silicon cells, and a heat observer plate in backside is welded, using tin, parallel tubes intended for the circulation of the working fluid. The solar cells are inserted in encapsulated materials, which included on the top the transparent TPT (Tdlar- polys tertedlar) and EVA (ethylene–vinyl acetate), and the bottom part The system consists many in addition principal components, storage tank, and some auxiliary equipment's such as insulated pipes, water pump electrical storage battery, inverter and differential controller. See fig 2.7. According to energy demand analysis the system will be titled at the optimized operation point to give the required electrical power and hot water. Since the water based PV/T systems are convenient generally for household hot water needs and can serve efficiently at any time of year, mostly in low latitude regions, because water in communal pipeline is typically below 20°C. Studies on PV/T water heating system usually focus on determining appropriate water flow rate and temperature, sizing of water tubes for optimization and structural configurations including parts, components, connections etc. At peak solar radiation availability, the system may operate at its maximum efficacy and energy may produce more than the demand and storage mechanism both for electrical power battery and the insulated for hot water will carefully designed. [17]

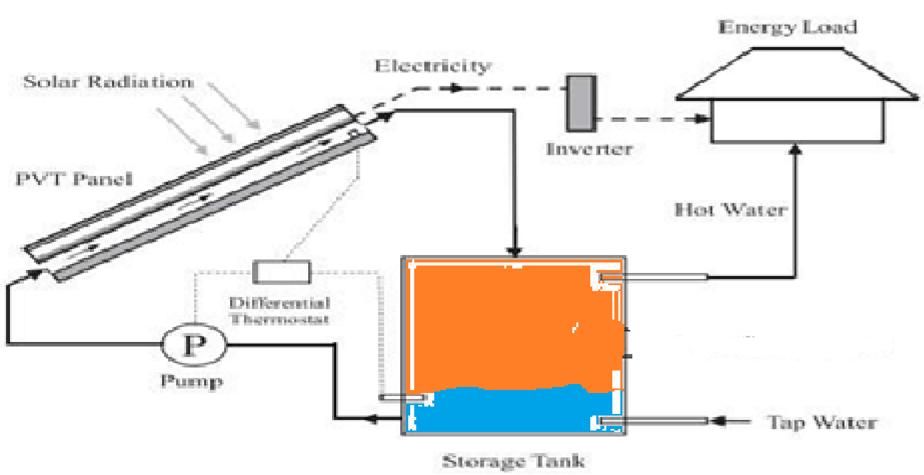

Figure 2.6: The System Description of Water Based PV//T

2.5 Evaluating System Performance of Water Based PV/T

The technical performance of the PV/T systems is frequently assessed using several analytical parameters such as overall energy efficiency, main-energy-saving effectiveness, and solar fraction. While, the economic performance of the PV/T systems is measured with Life Cycle Cost (LCC) and Cost Payback Time (CPT), and the ecological benefit of the system is justified using the Energy Payback Time (EPBT) and Greenhouse Payback Time (GPBT). To perform quantitative performance predictions of a hybrid PV/T system Bergene and Lovvik developed a physical model that predicted the performance of the system reasonably well obtaining overall efficiency in the range of 60–80%. [18].

Additionally, Dubey and Tiwari also developed an analytical model to describe the performance of multiple PV/T flat-plate collectors as a function of design and climatic parameters. A water PV/T collector predominantly combines the characteristics of a flat-plate solar (thermal) collector, sheet and tube heat exchanger and those of a PV module. Therefore, in assessing the performance of the PV/T collector, it is prudent to look at the two systems separately and after consider the overall combined effect. [19]

2.5.1 Electrical Performance Assessment of PV/T

The PV generator consists of a collection of solar cells connected either in parallel or series or combination of both, connecting leads, guarding parts and supporting frame. The solar cell is made of distinctly conditioned semi-conductor material forming an electric field with positive and negative sides on the back and front sides respectively. When these two sides of the solar cell are linked by means of a load, flow of electric current (photon current Ip) is initiated provided it is exposed to sunlight. On the other hand, in the absence of sunlight, the solar cell is inactive and functions as a diode which when connected to a large external voltage source, produces a dark or diode current (Id).The typical PV cell configuration circuit diagram can be represented diagrammatically. As can be seen, there is a current source Ip, a diode and a series resistor Rs equivalent to internal resistance of the cell. The shunt resistance represents the internal resistance of the diode. [19]

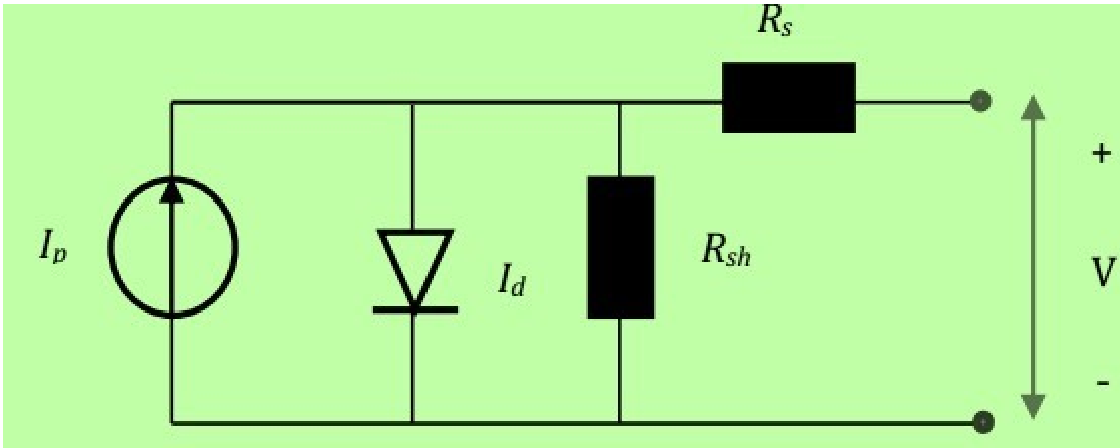

Figure 2.7: The equivalent circuit diagram of the system

Electrical efficiency of the PV panel is defined as the ratio of maximum electrical power output to the incident light power and is inversely proportional to the temperature i.e. it is reduced when the temperature increases. This is express in the following form.

$$\eta_{\max} = \frac{P_{max}}{Pin} = \frac{Imax * Vmax}{PinA} --------- Eq(2.10)$$

2.5.2 Thermal Performance Assessment of PV/T.

The thermal performance of the flat-plate solar collector is defined by the Hottel-Whiller–Bliss thermal efficiency equation. The expression has gained widespread application in the design, modeling and simulation performance assessment of solar systems. The aggregate heat absorbed by the collector Qu, is conventionally expressed as the product of mass flow rate, specific heat capacity of the cooling fluid and the temperature difference of the fluid at outlet and inlet as given in equation.

$$Qu = \dot{m}cp(Tout - Tin) ---------- Eq(2.11)$$

The heat source for the collector is the solar radiation and therefore, when this is considered, the expression for the useful energy Qu is given as:

$$\eta max = \frac{Qu}{GAc} -------------- Eq(2.12)$$

2.6 Overall Energy Efficiency

The ratio of collected electrical and thermal energy to incident solar radiation striking on the PV/T absorber gives the overall energy efficiency. In comparison, electrical efficiency of a PV/T module is more inferior to its thermal efficiency. This fact implies that, when the thermal energy conversion efficiency increased, then the overall energy efficiency of the system is also improved. It is worth noting that, the overall energy efficiency disregards or does not take into account the difference between heat and electrical energy qualities hence, it is insufficient to completely warrant a good performance by PV/T systems. The overall efficiency of a PV/T system can be calculated as the sum total of the electrical and thermal efficiencies. [21]

2.7 Literature Summery

In case of our country I have try to get similar works even though there is no written by native scholar on PV/T, I have got some partially similar research done by Gelma Boyena developed design of a Photovoltaic/ Wind hybrid Power generation system for Ethiopian remote area. This may be mention as good work in solving off-grid energy problem of our great population.as it has described and reviewed above. The aim of this work is to design and optimized the analytical study of the thermal and electrical performances of a hybrid water based PV/T water collector for off-grid purpose using Matlab.

CHAPTER THREE

3. ASSESSMENT OF TOTAL ENERGY DEMAND AND ESTIMATION SOLAR RADIATION

3.1 Estimation of Energy Demand for the Selected Household

Energy Plea Charge and Load Preparation of the selected site are based on almost ideal energy assessment system which is considers logical energy audit. The population who lives in the selected residential homes are expected to use appliances includes lighting, TV, refrigerator, radio receiver, cooking stoves, steam bath and some additional annual ceremonial.

3.1.1 Electrical Consumption

The electrical energy and hot water produced from the proposed hybrid system is supplied to cover the total demand described above as much as possible with respect to the relative cost. Even though the energy demand is extremely sensitive variable, for simplicity in this thesis it is considering that, medium residential households with the life standard in developing countries. All energy consumption is taking as energy expenditure.

Table 3-1: Electric Consumption

End Use Device	C Power (W)	Quantity	C hour (KW)	Averag e hpd	CPD (KWh)
Lighting	11	4	0.044	6	0.264
TV	100	1	0.1	5	0.125
Refrigeration	200	1	0.2	10	2
Stove	1000	1	1	2	2
Laptop and Mobile Cell	200	3	0.2	5	0.5
Total	2511	8	2.544	27	4.845

3.1.2 Assessment of Hot Water Consumption in Household

Domestic hot water consumption is also key variable, for the design and planning heating system. In house hold hot water has very critical advantage. Almost all activates needs the active catalyst of hot water. Typically, domestic uses of hot water include cooking, cleaning, bathing, and seasonal space heating. The average consumption in Ethiopian household hot water is estimated as depending the hourly activates and the degree of temperature of the heat water. To determine the exact point within the dwelling where water was consumed a many parameters has considered. Many researchers have been conducted before many years ago around the world especially in the developed counters. Since the energy consumption indicates show that 25% energy in investing for the domestic hot water consumption. It has significant number as the whole of the national level of energy demand. Even though it not possible to get such research's which was done inside country, in this paper try to consider the actuality of this hot water consumption assessment. The estimation method of hot water demand and related energy demand based on Standard, Design, installation, testing and maintenance of services supplying water for domestic use within buildings and based on the expected number of occupants (N) which is in turn related to the total floor area (TFA) [23]

The standard number of occupants, N is given by:

$$\text{if TFA} \leq 450\ \text{m}^2, \text{N} = 0.0365\ \text{TFA} - 0.00004145 \text{ x TFA}^2$$

$$\text{if} \quad \text{TFA} > 450, \text{N} == 9/(1 + 54.3/\text{TFA})$$

After determine the number of persons the consumption hot water is used based on better, Variables that had high correlation with other independent variables were not used. To find the optimal set of explanatory variables for the accepted model the following parameters are taken as the dominant factors.

i. Outside ambient temperature,
ii. Temperature inlet water of the water heater the system,
iii. Thermostat setting of the lower heating element of the water heater,
iv. Size of the tank,
v. The number of people within a household, divided into three age groups,
    - Infants and young children (through age seven)
    - Children (ages six to 15),
    - Adults (ages 16 and older)
vi. A dummy variable for an unemployed household member;
vii. Four dummy variables, one for each season

Dummy variables indicate the occurrence or absence of a condition. The value of the dummy variable for an unemployed household member would equal one, if one or more unemployed member of the household stayed home during the day and would equal zero for any other situation. Dummy values for each season are set equal one for the season in question while the other seasons' values are set to zero. [18]. James D. Lutz, James E. McMahon, was done a research and devolved a good model for estimating hot water consumption for house hold as expanded statistical method. [19]

The general arrangement of the model is given below

$$\text{Uload} = [\text{Co} + C_1 \times \text{Per} + C_2 \times \text{Age}_1 + C_3 \times \text{Age}_2 + C_4 \times \text{Age}_3 + C_5 \times \text{therm} + C_6 \times \text{tank} \quad -------------\text{Eq}(3.1)$$

The constants are varied depending the hour of day which related staying time in home.

Where U_{load} is hot water consumption, (L/hr.), Per is number of persons in household, Age_1 number preschool children (0-5 yrs.) Age_2 number of school age children (6-13 yrs.) Age_3 number of adults (14 yrs. and over), Therm is solar water heater lower setting, (°C) and Tank is water heater nominal tank size, (L);

Where: C_1, C_2, and C_n is constants which are varied from depending on a lot conditions and this leads to restrict the consumption value of the limited pattern.

Obviously, the behavioral study on consumers or customers shows that the degree of consumption for some product is directly related with their income and life standard. Some things are essential needs for someone and be luxuries for others. For many circumstances, hourly-use arrangements are not crucial and average daily hot water use is more acceptable. A single equation for average daily hot water use throughout the year can be derived by summing the coefficients for all the terms in the detailed model equation. This simplified equation has the same general form as the detailed model shown in Equation(3.1).The coefficients have been weighted by the number of hours and number of days each term is used in a full year. The variables have the same meaning as in Equation (3.1) [20]

$$\begin{aligned} U_{load}\left(\frac{L}{day}\right) = \{&18 + 3.7 * \text{per} + 24.2 * \text{age1} + 39.8 * \text{age2} + 57.9 * \text{age} - 0.87 * \text{therm} \\ &+ 0.144 * \text{tanksz} - 1.222 * \text{wtmp} + 3.485 * \text{atmp} + 38.7 * \text{athome} \\ &- \left(2.62 * \text{per} + 5.05 * \sqrt{\text{per}}\right), \text{if no dishwasher} \\ &- \left(4.424 * \text{per} + 18.070 * \sqrt{\text{per}}\right)\}, \text{if no clothes washer} ------\text{Eq}(3.2) \end{aligned}$$

Taking to consider the middle size house hold which has 5-7 persons with the context of our country and using the above equation the average daily hot water consumption is 250 Litter at 45 degrees centigrade.

3.2 Assessment of Solar Radiation Availability

Once the energy demand is determined by summing the electrical and hot water consumption, the next duty will be creating the energy supply for this demand. Assessment of solar radiation availability is the backbone on the design of any solar system, since it is high significant input variable. Solar radiation data are available in several forms for a Varity of purposes. The most detailed information available is beam and diffuse solar radiation is on horizontal surface. They are instantaneous measurement (irradiance) or values integrated over some period of time (irradiation) usually hour or day. In this paper it will focuses on hourly estimation the solar availability, since each hour has its own energy demand [7]. The estimation solar radiation may be carried out using experimental measurement and analytical method based on geographic location of the site relative to position of the sun. It well known that experimental measurements have great honesty in their output, but this method has not affordable in cost and analytical method with helping of metrological data is getting more priority.

3.2.1 Estimation Beam and Diffuse Solar Radiation

When the sun emitted solar radiation some part of its reach to earth surface directly and counts as beam radiation. And the remaining part is scattering radiation. As it passes through the atmosphere it makes interaction with air molecules, water (vapor and droplets), and dust. The degree to which scattering occurs is a function of the number of particles through which the radiation must pass and the size of the particles relative to λ, the wavelength of the radiation. And this count as diffuse radiation. The fragmented of aggregate solar radiation on a horizontal surface into its diffuse and beam components are of interest in two contexts. First, methods for calculating total radiation on surfaces of other orientation from data on a horizontal surface require separate treatments of beam and diffuse radiation. Second, estimates of the long-time performance of most solar system collectors must be based on estimates of availability of beam radiation. The present methods for estimating the distribution are based on studies of available measured data; they are adequate for both the first purpose and for the second. [7]

Hottel (1976) has presented a method for estimating the beam radiation transmitted through clear atmospheres which takes into account zenith angle and altitude for a standard atmosphere. The beam radiation is calculated. [21]

$$G_{cnd} = G_{on} * \tau_b \text{ ----------------- Eq(3.3)}$$

Where: G_{on} is intended as

$$Gon = Gsc\,(1.00011 + 0.0342\cos(\beta) + 0.001280\sin(\beta) + 0.000719\cos(2\beta) + 0.000077\sin(\beta)) \text{ ----------- Eq(3.4)}$$

Where: Gsc is 1367 Kw/m^2.

T_b is atmospheric transmittance which explained as follows

$$\tau_b = a_0 + a_1\left(\exp\left(\frac{-k}{\cos\theta z}\right)\right) \text{ ----------- Eq(3.5)}$$

The constants ($\mathbf{a_0}$, a_1 and k) for the standard atmosphere with 23 km visibility are found as follows the correlation

$$a_0 *= 0.4237 - 0.00821 * (6 - A)^2$$
$$a_1 *= 0.4237 - 0.00821 * (6.5 - A)^2$$
$$k *= 0.4237 - 0.00821 * (2.3 - A)^2$$

Where A is the altitude of the observer in kilometers and the constants are found from Correction factors are applied to a^{0*}, a^{1*} and k^* to allow for changes in climate types. The correction factors $r_0=a^0/a*0$, $r1=a^1/a*^1$, and $r_k = k/k*$ are given in Table 3.2. Thus, the transmittance of this standard atmosphere for beam radiation can be determined for any zenith angle and any altitude up to 2.5 km.

Table 3-2: Correlation Factor for Climate Type

Climate	Ro	r1	Rk
Tropical	0.95	0.98	1.02
Mid latitude summer	0.97	0.99	1.02
Subarctic summer	0.99	0.99	1.01
S Mid latitude winter	1.03	1.01	1.00

Farber and Morrison (1977) provide tables of beam normal radiation and total radiation on a horizontal surface as a function of zenith angle. [22] Also Liu and Jordan (1960) developed an empirical relationship between the transmission coefficients for beam and diffuse radiation for clear days. Similar to this we can also define a daily clearness index K_T as the ratio of a particular day's radiation to the extraterrestrial radiation for that day. In equation form,

$$K_T = \frac{H}{Ho} --------------------- Eq(3.6)$$

And the hourly clearness index could be calculated as

$$k_T = \frac{I}{Io} ---------------------- Eq(3.7)$$

The usual approach is to correlate the fraction of the hourly radiation on a horizontal plane which is diffuse, with (k_T), the hourly clearness index. For relating this Orgill and Hollands correlation has been, produces results that are for practical purposes, and is represented by the following equations.

$$\frac{Id}{I} = \begin{Bmatrix} 1 - 0.249\ k_T & \text{for } 0 \leq k_T \leq 0.35 \\ 1.557 - 1.49\ k_T & \text{for } 0.35 < k_T < 0.75 \\ 0.177 & \text{for } kT > 0.75 \end{Bmatrix} ---- Eq(3.8)$$

In clear-day data such as that suggest a diffuse radiation model as being composed of three parts. The first is an isotropic part, received uniformly from the entire sky dome. The second is circumsolar diffuse, resulting from forward scattering of solar radiation and concentrated in the part of the sky around the sun. The third, referred to as horizon brightening, is concentrated near the horizon and is most pronounced in clear [7].

3.2.2 Prediction of Average Daily Global Radiation on a Horizontal Surface

The original Ångstrom type regression equation estimate monthly average daily radiation to clear day. Radiation at the location and average fraction of possible sunshine hours is given as.

$$\frac{\overline{H}}{\overline{Hc}} = a' + b'\frac{\overline{n}}{\overline{N}} ---------------- Eq(3.9)$$

Where;

$\overline{H}$ is monthly average daily radiation horizontal surface.

$\overline{Hc}$ is average clear -sky daily radiation horizontal surface.

a' and b' empirical formulas

$\bar{n}$ is monthly average of maximum possible daily hours of bright sunshine.

Norris (1968) reviewed several attempts to develop such a correlation.[23] Bennett (1965) compared correlations $\left(\frac{\mathbf{H}}{\mathbf{Ho}}\right)$ with $\left(\frac{\bar{\mathbf{n}}}{\bar{\mathbf{N}}}\right)$ and with a combination of the two variables.

$$\frac{\overline{H}}{Ho} = a + b\frac{\overline{n}}{\overline{N}} - - - - - - - - - - - - - - Eq(3.11)$$

Where:

(**$\acute{\overline{Ho}}$**) daily extraterrestrial radiation on a horizontal surface rather than on clear-day radiation: is calculated as.

$$Ho = \frac{24+3600Gsc}{\pi}\left(1 + 0.033\cos\frac{360N}{365}\right)\left(\cos\varphi\cos\delta\sin\omega\mathbf{s} + \frac{\pi\omega s}{180}\sin\varphi\sin\delta\right) - - (Eq3.12)$$

3.2.3 Prediction of Average Hourly Global Radiation on a Horizontal Surface

Arithmetical revisions of the time delivery of total radiation on horizontal surfaces through the day using monthly average data for a number of stations have led to generalized charts of r_t, the ratio of hourly total to daily total radiation, is found as a function of day length and the hour in question

$$rt = \frac{I}{H} - Eq(3.13)$$

Collares Pereira and Rabl (1979) has been developed the formula to estimating this ratio as function of length of the day.

$$rt = \frac{\pi}{24}(a + b\cos\omega)\frac{\cos\omega - \cos\omega s}{\sin\omega s - \frac{\pi\omega s}{180}\cos\omega s} - - Eq(3.14)$$

The coefficients a and b are given by:

$$a = 0.409 + 0.5016\sin * (\omega s - 60)$$

$$b = 0.6609 - 0.4767\sin * (\omega s - 60)$$

In these reckonings (ω) is the hour angle in degrees for the time in question (i.e., the midpoint of the hour for which the calculation is made) and (ωs) is the sunset hour angle.

3.3 Total Solar Radiation on Sloped Surface

So far we try to estimate the radiated energy from the sun as beam and diffuse on the horizontal plane as monthly, daily and hourly average but it is necessary to know or to be able to estimate the solar radiation incident on tilted surfaces such as solar collector. The incident solar radiation is the sum of a set of radiation streams including beam radiation, diffuse radiation from the sky, and radiation reflected from the various surfaces ‘‘seen’’ by the tilted surface. Look the fig 3.2 below The total incident radiation on this surface can be written as:

$$I_T = I_b + I_d + I_{rf} - - - - - - - - - - - - Eq\ (3.15)$$

Different researches uses different model to calculate the total radiation on sloped surface using better estimation and less complexity. Liu and Jordan (1963) was developed the isotropic diffuse model, according to his hypostasis the radiation on the tilted surface was considered to include three components: beam, isotropic diffuse, and solar radiation diffusely reflected from the ground.

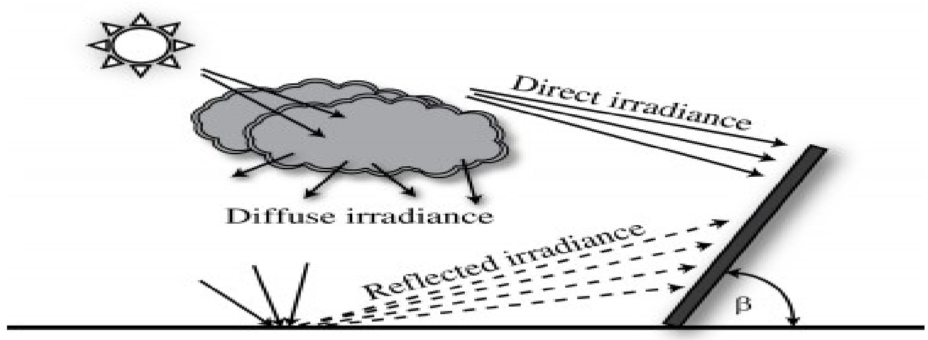

Figure 3.1: Solar Irradiance on Sloped Surface

A surface tilted at slope β from the horizontal has a view factor to the sky (Fc−s = (1+cosβ)/2). (If the diffuse radiation is isotropic, this is also Rd, the ratio of diffuse on the tilted surface to that on the horizontal surface), which is calculated as function of the angles as follow: [24]

$$R_b = \frac{cos\theta}{cos\theta z} ------------------ Eq\ (3.16)$$

Where: θ and θz is find in the angles in section 2.1.2.Considering different slop angle this conversion factor varies the value (R_b) depending day of the year as well as the tilted angle. This may have described the variation of total solar radiation. The tilted surface has a view factor to the ground ($F_{c-g} = (1 - cos\beta)/2$) and if the surrounding have a diffuse reflectance of (ρg) for the total solar radiation, the reflected radiation from the surroundings on the surface will be ($I_{pg} = (1 - cos\beta)/2$). Thus Equation 3.15 is modified to give the total solar radiation on the tilted surface for an hour as the sum of three terms:

$$I_T = I_b R_b + I_d\left(\frac{1 + cos\beta}{2}\right) + I_{\rho g}\left(\frac{1 - cos\beta}{2}\right) -- Eq\ (3.17)$$

This model is easy to appreciate, and makes design of fall out on slanted outsides easy. But it has some drawback on the estimation diffuse. To improve this Hay-and-Davies models have been developed model which take into account the circumsolar diffuse and/or horizon- brightening components on a tilted surface. Hay and Davies (1980) estimate the fraction of the diffuse that is circumsolar and consider it to be all from the same direction as the beam radiation based on the assumption that all of the diffuse can be represented by two parts, the isotropic and the circumsolar.

The diffuse radiation on a tilted collector is written as;

$$I_{dT} = I_d\left[(1 - Ai)\left(\frac{1 + \cos\beta}{2}\right) + AiR_b\right] ----Eq(3.18)$$

Where: Ai is an isotropy index which is a function of the transmittance of the atmosphere for beam radiation

$$Ai = \frac{I_b}{Io} ----------------- Eq(3.19)$$

Then the total solar radiation becomes:

$$I_T = (I_b + I_d Ai)R_b + I_d(1 - Ai)\left(\frac{1 + \cos\beta}{2}\right) + I\rho g\left(\frac{1 - \cos\beta}{2}\right) --- Eq(3.20)$$

Hay and Davies (1980) estimate the fraction of the diffuse that is circumsolar and consider it to be all from the same direction as the beam radiation; they do not treat horizon brightening. Reindl (1990) add a horizon brightening term to the Hay and Davies model, as proposed by Klucher (1979), which giving a model to be referred to as the HDKR model [7]. Even though there are additional models that improved the above models but for more representation of our geographical location in this thesis it takes the HDKR model since it is almost as simple to use as the isotropic and produces results that are closer to measured values. For surfaces sloped toward the equator the HDKR model is suggested.

$$I_T = (I_b + I_d Ai)R_b + I_d(1 - Ai)\left(\frac{1 + \cos\beta}{2}\right)[1 + f\sin^3\left(\frac{\beta}{2}\right) + I\rho g\left(\frac{1 - \cos\beta}{2}\right) - -Eq(3.21)$$

Where: Ai is as defined by Equation (3.19) and f is modulating factor which is defined as in terms of the beam radiation.

$$f = \sqrt{\frac{Ib}{I}} -------------------- Eq (3.22)$$

3.4 Estimation of Total Solar Radiation for the Selected Site

Ethiopia is geographically located between 33° and 48° E longitudes and between 3° and 15° North's which is within the solar belt. The catchment covers an area of 5133 sq. km with an elevation ranging from 955 m to 4000 m with a mean elevation of 2164 m above sea level [A. Z.] Abraha, northern Ethiopia," PhD thesis, KUL, Leuven, 2009]. The catchment's geographical coordinates are 38°38' to 39°48' E (longitude) and 13°18' to14°15 N (latitude) [15]. The raining season of this catchment is from end of July to beginning of September the remaining of the year with clear sky. According to the A.Z. Abraha assessment there is no below 3.5 $kWh/m^2/d$ for four selected site in north Ethiopia. Other assessment also conducted in Gambella region which indicates the minimum total solar radiation 4.25kwh/m^2d. [26].

In general, as it has described in the research background Ethiopia has good resource of solar energy for its location around equator. The solar radiation is calculated for the complete country for the years 2000, 2001 and 2002. The data are made available in a digital GIS-format (ESRI Vector-Shape file). Within this report, maps of the annual average daily total sum of GHI and DNI are presented. The complete database (ESRI-Shape file and MS-Access database) can be downloaded from the SWERA-homepage (http://swera.unep.net) [27].

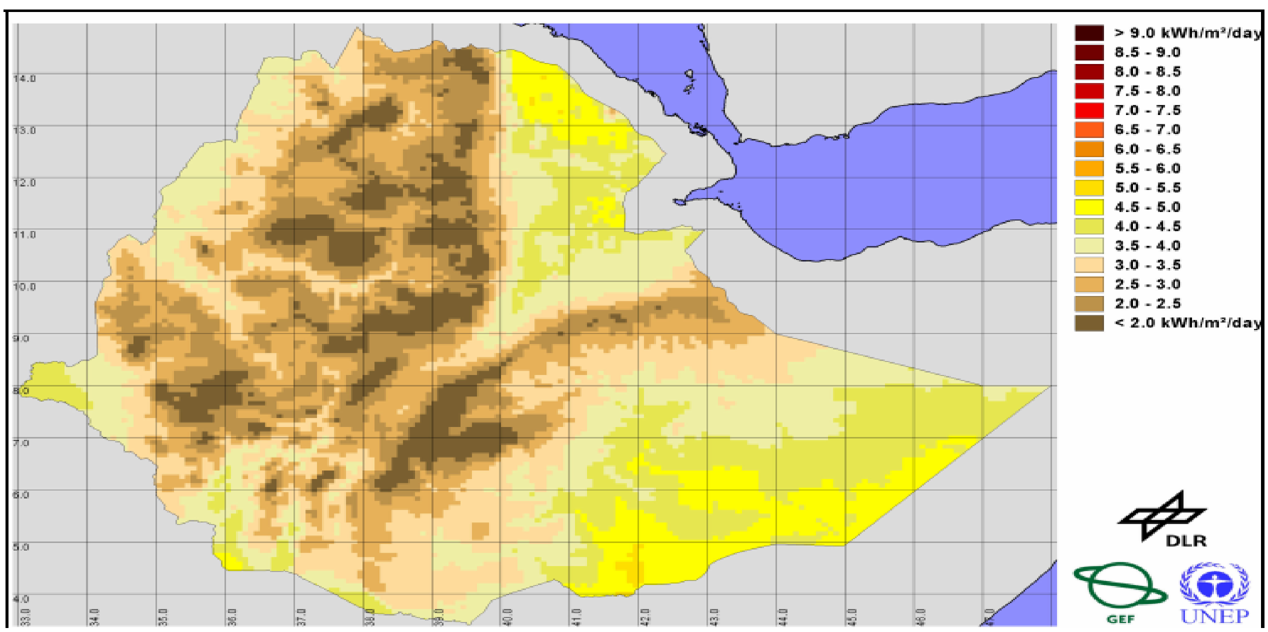

Figure 3.2: Annual Total Solar Radiations in Ethiopia

For the purpose of simulation, the result of the thesis we selected off-grid remote rural village in which is located at latitude 13.5^0N and longitude 38.45^0E and has an average elevation of 1867m meters above sea level [Ret screen NASA data based with tolerating error 2%]. The site has minimum total solar radiation 5.53 Kwh/m^2d at July and ambient temperature 19.1^0c at august and maximum total solar radiation at March 6.48 Kwh/m^2d and ambient temperature 23^0c.

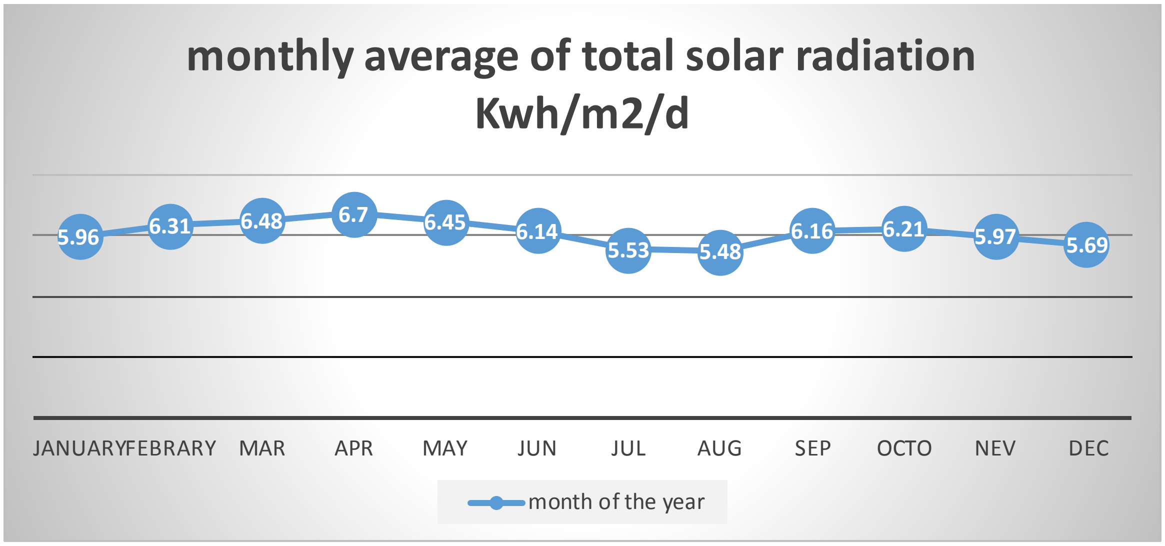

Figure 3.3: Monthly Average Solar Radiation

CHAPTER FOUR

4. CONCEPTUAL DESIGN AND THEORETICAL ANALYSIS OF WATER BASED PV/T

4.1 Principal Components of System Water Based PV/T and Description

The proposed PV/T water heating system is schematically shown below. The system comprises of clean tempered glass on the top, a group of PV cells in the middle, a treated Al-alloy sheet at the back and two layers of ethylene-vinyl acetate (EVA), electricity control/storage unit, fluid hot water/liquid transportation lines, and a hot water tank, water pump, the water tank and an expansion valve. The sheet–tube solar collector is a specific heat exchanger configured with external fins, the pipe enables to rise water temperature to take place on its inner surface when receiving heat from PV on the outer surface.

4.2 Design Components of Water Based PV/T

This subtopic grants the parametric offer of the different system components with certain alternative varying ranges, including the glazing cover, PV layer, fin and sheet-tube solar collector, storage tank. The parametric data will be further applied as the input figures for the modeling and optimization in subsequent chapters.

4.2.1 Glassing Cover

The glazing cover of the water based PV/T module is significant to the overall absorption of solar energy because it can maximize the amount of solar absorption and minimize heat loss. It also protects the water based PV/Module from external damage. Glass, the material most commonly used as a cover material in solar collectors, may absorb little of the solar energy spectrum if its Fe_2O_3 content**.** If its Fe_2O_3 content is greater than the design limit it will absorb in the infrared portion of the solar spectrum. Since the transmittance of the glass is inversely related with its thickness it not recommended being more than 3mm [7]. And increasing the number of glazing covers will have the opposite effect of reducing the input of solar radiation due to the glazing transmittance. According to experimental investigation number of glass greater than two has been decreasing the glazing transmittance [3].

Figure 4.1: Cover Glass

Table 4-1: Parameters of Glass

Glass Parameters	
Thickness	0.003m
Mass density	2530 kgm^-3
Specific heat capacity	836 J. k^-1.m^-1
Thermal conductivity	0.93 WK^-1m^-1
Extinction coefficient	0.2cm^-1
Transmission	0.93
Emissivity	0.83
Distance between the glass and pv	0.045m

4.2.2 PV Panel of the Collector

With the evolution of photovoltaic technology different semiconductor materials have been used to make the layers in different types of solar cells, and each material have its own quantities and drawbacks. The first requirement of a material to be suitable for solar cell application is a band gap matching to solar spectrum. The band gap should be between 1.1 and 1.7 eV. The material must also have high motilities and lifetime of charge carriers. And Other requirements are:

- Direct band structure.
- Consisting of readily availability.
- Non-toxicity, and easy reproducible deposition technique,
- Suitable for large area production,
- Good photovoltaic conversion efficiency and long-term stability

The highest efficiencies achieved using the different semiconductor materials are given in below table ref [10]. Roger and Ventre, (2005). Investigated the theoretical conversion efficiency limits for several PV materials. When solar irradiance strikes the solar cell, the light photon is absorbed by a valence electron increasing its energy by the amount of energy of the photon.

$$\mathrm{Ep} = \mathrm{hpf} = \frac{\mathrm{hpc}}{\lambda}(\mathrm{joules}) = \frac{1.24}{\lambda\mu\mathrm{m}}(\mathrm{eV}) \text{ ---------- } \mathrm{Eq}(4.1)$$

Based on this formula some materials are estimated their energy gap with respect to wave length of the radiation.

Table 4-2: Energy Gap and Efficiency of Different Materials

Material type	**Ge**	**CIS**	**Si**	**InP**	**GaAs**	**CdTe**	**AlSb**	**a-Si**	**Cds**
Energy gap	0.6	1	1.1	1.2	1.4	1.48	1.55	1.65	2.42
ηmax%	13	24	27	24.5	26.5	27.5	28	27	18

If the energy of the photon is equal to or larger than the band gap of the semiconductor, the electron with excess energy will jump into the conduction band. The excess energy over the band gap increases the kinetic energy of the photon. But, if the photon energy is less than the band gap, the electron will not be able to jump into the conduction band and the excess energy gained is dissipated as heat which increases the cell temperature as soon as the produced electrical energy is less.

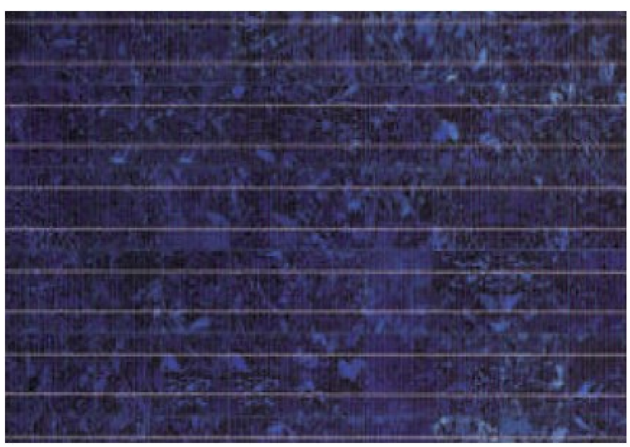

Figure 4.2:p-si Pv Module

In addition to this inherent property of those semiconductor materials, Zhang proposed that the effect of coating alloy over those materials to increase thermal conductive. For this purpose, AL-alloy PV is good in contrast with a conventional PV TPT baseboard, for its advantages of a much higher thermal conductivity (154 W/m-K versus 0.648 W/m-K), a higher solar absorptance (5%

versus 2%), a lower solar transmittance (0.2% versus 12.8%) and a lower reflectance of solar beams in the wavelengths of 340-1100 nm .The coated Al-alloy sheet was designed to be 0.65 mm thick, which not only served as an electrical insulation device, but also protected the baseboard from corrosion during its life-cycle operation.

Table 4-3: Parameters of Al-Alloy

Parameters	Value	Unit
Thickness of Al-Alloy	0.65	Mm
Thermal Conductivity of Al-Alloy	154	w/m-k
Solar Absorptance of Al-Alloy	5	%
Nominal Efficiency	16.5	%
Solar Transmittance of Al-Alloy	0.3	%
Packing Ratio	0.9	%

4.2.3 Selective Surface of the Thermal Collectors

Solar thermal collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The collector plate absorbs as much of the irradiation as possible through the glazing and Module while losing as little heat as possible upward to the atmosphere and downward through the back of the casing. The collector plates transfer the retained heat to the transport fluid. To maximize the energy collection, the absorber of a collector should have a coating that has high absorptance for solar radiation (short wavelength) and a low emittance for re-radiation (long wavelength). Such a surface is referred as a selective surface.

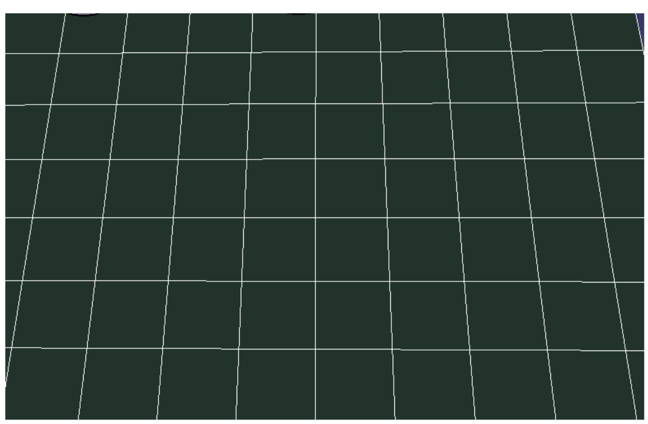

Figure 4.3: Selective Surface for Absorbance

The absorptance of the collector surface for short wave solar radiation depends on the nature and color of the coating and on the incident angle. Usually black color is used. The materials most frequently used for collector plates are copper, aluminum and stainless steel. UV-resistant plastic extrusions are used for low-temperature applications. [3]

4.2.4 Sheet –Tube Water Heater

This is the principal component on the achievement of the output both primary electrical energy gains by extracting the excess heat energy from PV module and producing the desired hot water.
To design and construct solar collectors for water heating, detailed knowledge of the properties of the materials and the characteristics of the various components is necessary to predict the performance and durability of the collector like thermo-physical, (thermal conductivity,

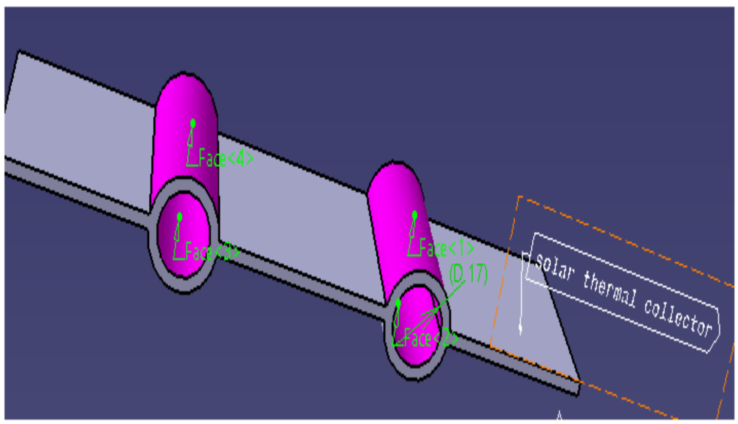

Figure 4.4: Sheet-Tube Solar Thermal Collector

heat capacity and radiant), Physical (include density, tensile strength, melting point). The collector absorber plate should have high thermal conductivity, adequate tensile and comprehensive strength, and good corrosion resistance. For better heat transfer rate Stainless steel or steel aluminum or copper fins with stainless steel pipes Copper tubes extended to copper fins are recommended from point view material property.
There are different types of thermal collectors in the configuration the plate and tube and based of geometry design, among them sheet-tube the most effective in many factors. Sheet-and tube solar water heater is made up of parallel tubes on the back of the plate for collector. Hottel, Whillier and Bliss have shown that the generalized relationships developed for the tube-and-sheet case apply to most collector designs. It is necessary to derive the appropriate form of the collector efficiency.

4.2.5 Insulation Material

Insulation materials has the great impact on effectiveness of heat transfer rate. The back insulation of a flat plate collector is made from fiberglass or a mineral fiber mat that will not outgas at elevated temperature to controlling of heat lost properly for the achieving the set object, insulation material such as fiber glass, polyurethane foam and polystyrene board, are applied to minimize the heat loss of the system components. The efficiency of the insulation material is measured by its thermal resistance (R value). A larger R-value results in higher insulating effectiveness.

Table 4-4: lists the R-Values of Some Insulation Materials

Insulation material	**Thermal resistance(K-m^2/k)**
Polyurethane foam	0.986-1.356
Fiber glass	0.546-0.616
Polystyrene boards	0.634-0.9333

CHAPTER FIVE

5. TRANSIENT ANALYSIS AND PERFORMANCE EVALUATION

5.1 Transient Heat Transfer and Fluid Theory of Water Based PV/T

In the conversion of solar radiation to useful energy electrical and hot water there are some fundamental heat transfer mechanisms and some basic fluid mechanics theories. In the heat transfer part, it includes the consideration mechanisms of heat transfer radiation, convection and conduction. On other side the theory fluid mechanics is crucial part to integrate the properties of the fluid water and air with system. Based on this we develop the mathematical model for the PV/T collectors. The important parts of a liquid heating flat plate PV/T collector are the cover system with one glass, PV module, a plate for absorbing incident solar energy, parallel tubes attached to the plates and edge and back insulation. The analysis of the flat plate solar collector in this chapter is performed based on the configuration shown figure below [12].

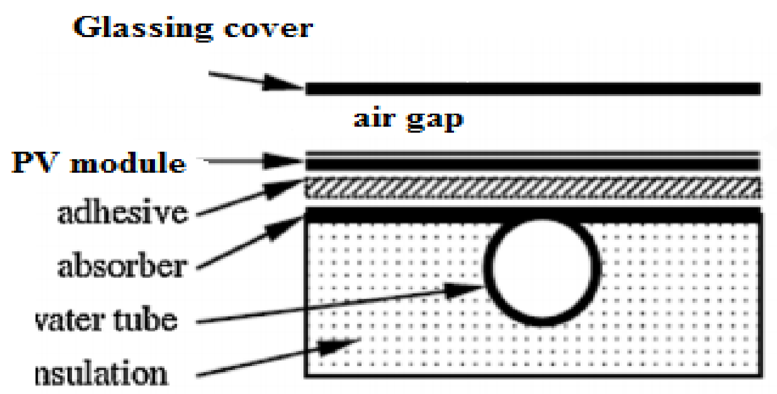

Figure 5.1: Cross Section View of the PV/T Collector

Some assumptions made to model the flat plate PV/T collectors are the following:

1. The PV/T collector tilted at optimized angle and operates in transient state model.
2. Construction is of sheet and parallel tube type.
3. The headers provide uniform flow to tubes.
4. There is one-dimensional heat flow through the back and side insulation and through the cover system.

5. Temperature gradients in the direction of flow and between the tubes can be treated independently.
6. Dust and dirt on the collector are negligible.
7. Shading of the collector absorber plate is negligible.

5.2 Determine of Heat Transfer Coefficient and Total Loss

In the determination of amount of energy transmitted from one component to the other it basically important to know coefficient factor or multiplier for heat transfer and effectiveness of any system in the given configuration such as total loss of the system. To do this determination of heat transfer loss is the first duty. Those are;

- Top heat loss
- Back heat loss

5.2.1 Top Heat Loss through the Cover System

To evaluate the heat loss through the cover system, all of the convection and radiation heat transfer mechanisms between parallel plates and between the plate and the sky must be considered. The collector model has one cover which is made of glass.

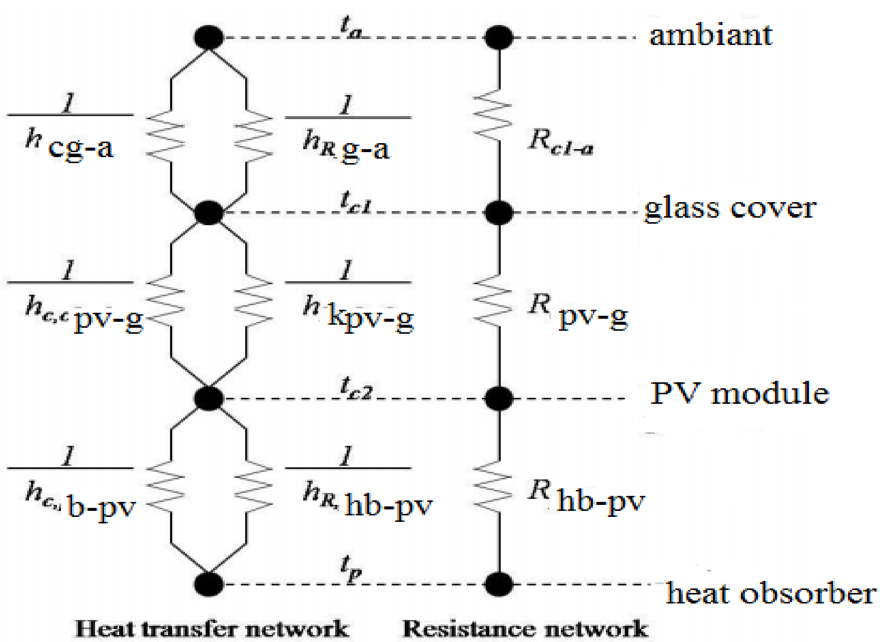

Figure 5.2:The heat transfer coefficients and resistance network

a) Convective Heat Transfer Coefficients

Convective heat transfer coefficients due to the wind from the glass cover to ambient is given according to McAdams by the relation:

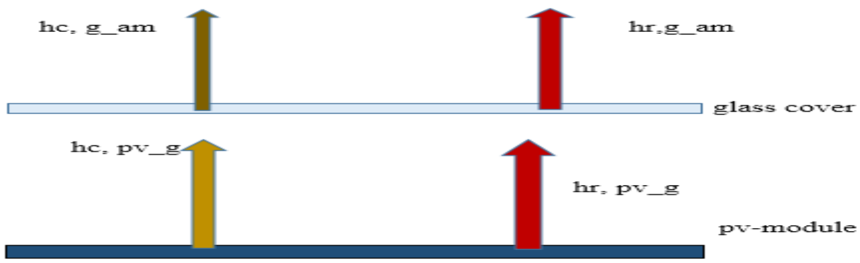

Figure 5.3: Top heat Loss coefficient from Pv-Module to the Ambient

$$h_{c1} = hc, g_{am} = V_{vent} * 3.8 + 5 ------ Eq(5.1)$$

Where: Vvent = is the wind velocity ($m.s^{-1}$)

Approximately to this equation for surface exposed to the outside wind, the convective coefficient could be calculated using the Klein equation:

$$hc, g_{am} = \frac{8.6Vvent^{0.6}}{L^{0.4}} ------------ Eq(5.2)$$

Where L is the characteristic length of the collector (m). From the pv module to glass cover convective heat transfer coefficients will be calculated as natural convective heat transfer coefficient between the glass and the PV is given by the expression.

$$hcg - pv = \frac{Nu * k_{air}}{b} ---------- Eq(5.3)$$

K_{air} is the thermal conductivity of the air b is the distance between the glass and the PV. And Nu is the Nusselt number calculated by using the following correlation.

$$\text{For } Gr < 1700 + 47.8\beta, Nu = 1.013 -------- Eq(5.4)$$

$$\text{For } Gr > 80000, Nu = 2.5 + 0.0133(90 - \beta) --- Eq(5.5)$$

otherwise:

$$Nu = [0.06 + 3.310 - 4(90 - \beta)]Gr^{0.33} ----- Eq(5.6)$$

Gr is the Grash of number define as:

$$Gr = \frac{g\aleph\Delta Tb^3}{v2} ----------------- Eq(5.7)$$

Where: β is the inclination angle of the collector (°c).ℵ is the thermal dilation coefficient of air.

B) Radiation heat Transfer coefficients

Radiation heat transfer coefficients between the outside Glazing Cover to Ambient (h1r):

$$h_{1r} = h_{r_{g_{am}}} = \varepsilon g \sigma \frac{(Tg + 273)^4 - (T_{skt} + 273)^4}{Tg - Ta} --- Eq(5.8)$$

Where: Tsky=Tam-6

From Plate to cover (h_{2r})

$$h_{2r} = hr, pv\ \varepsilon_{eff}\sigma \frac{(Tp + 273)^4 - (Tg + 273)^4}{Tpv - Tg} -- Eq(5.9)$$

Where :$\varepsilon_{eff} = \left[\frac{1}{\varepsilon_{pv}} + \frac{1}{\varepsilon g}\right]^{-1}$ and the overall loss heat transfer coefficient becomes;

$$Ut = \left[\frac{1}{h_{2c} + h_{2r}} + \frac{1}{h_{2c} + h_{2r}}\right]^{-1} -------- Eq(5.10)$$

Conduction heat transfer coefficients in the various layers of the collector are obtained by the relation:

$$kc, n = \frac{kn}{\delta tk} ------------------ Eq(5.11)$$

Where: kn is the thermal conductivity of the layer. δ_{tk} is the thickness of the layer.

C) Convective heat Transfer coefficients between the tub and water

For De>> δi; taking the approximation of the reference. The heat transfers between the tubes and the working fluid is done by forced convection. For the circular piping, one can use the following correlations to determine the heat transfer coefficients by convection between the fluid and the tubes, $hv, t_{\_f}$ on the one hand and between the fluid and insulation hv, i_f on the other hand.

a) **In the case of a laminar flow:**

Re<2100- For Gz<100

$$Nu = 3.664 + \frac{0.085\, Gz}{1 + 0.045 Gz^{\frac{2}{3}}} \left[\frac{\mu_f}{\mu_b}\right]^{0.14} -------- Eq(5.12)$$

For Gz>100

$$Nu = 1.86 Gz^{\frac{1}{3}} + \left[\frac{\mu_f}{\mu_b}\right]^{0.14} + 0.87\left(1 + 0.01 Gz^{\frac{1}{3}}\right) ------ Eq(5.13)$$

$$hv, t_{\_f} = \frac{Nu * kt}{\sigma t} ---------------- Eq(5.14)$$

$$hv,i_{\_f} = \frac{Nu * ki}{\sigma i} ---------------- Eq(5.15)$$

b) **in case of a transitory flow**

$2100 < Re < 10000$

$$Tpv = 30 + 0.0175(G - 150) + 1.14(Ta - 25) ----Eq(5.16)$$

$$Nu = 0.116\left(Re^{\frac{2}{3}} - 125\right)[Pr]^{0.334} + \left[1 + \left(\frac{Di^{\frac{2}{3}}}{l}\right)\right]\left(\frac{\mu f^{0.14}}{\mu n}\right) --- \quad Eq(5.17)$$

c) **In the case of a turbulent flow**

$$Nu = 0.023(Re^{0.8})[Pr]^{0.334}]\left(\frac{\mu f^{0.14}}{\mu n}\right) ---------Eq(5.18)$$

Where: μ is the dynamic viscosity of the fluid at the temperature considered. Re, Pr, Gz is Reynolds, Prantdl Graetz numbers respectively. [13]

5.2.2 Back Loss Coefficient

a) **Edge Loss Coefficient**

Energy lost from the side of the PV/T collector casing may Energy lost from the side of the coll ector casing may be taken to have exactly the same value as that from be taken to have exactly the same value as that from the back, if the thickness of the edge insulation is the back, if the thickness of the edge insulation is the same as that of the back insulation (Tabor, 1958)

The edge loss is given as:

$$Ue = Ub\left(\frac{Ae}{Acp}\right) ------------------Eq(5.19)$$

Where: Ae is edge area and Acp is collector plate area.

b) **Bottom Loss**

Heat is lost from the absorber plate to ambient by conduction through the insulation and subsequently by convection and radiation from the bottom surface casing.

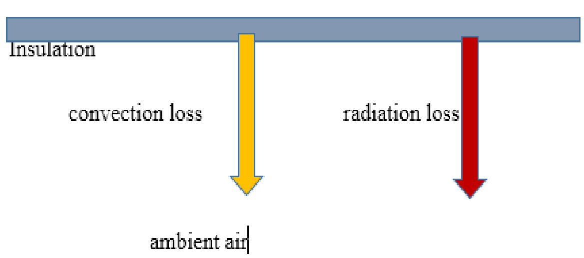

Figure 5.4: Heat Loss from Bottom Surface to the Ambient

The bottom loss coefficient is given by;

$$U_b = [\frac{Lin}{Kin} + \frac{1}{hb}]^{-1} --------------- Eq(5.20)$$

For negligible of the second term it will be becomes;

$$U_b = [\frac{Lin}{Kin}]^{-1} ---------------- Eq(5.21)$$

And finally the overall heat transfer loss becomes the sum of all losses is given by;

$$U_L = U_t + U_b + U_e -------------Eq(5.22)$$

This has the great impact on the production both electrical energy and hot water since it increased loss heat from the system to surrounding atmosphere for unit area this may this may be expressed as empirically.

$$Q_l = U_L(Tp - Ta) ------------ Eq(5.23)$$

5.3 Transient Energy analysis and Mathematical Modeling of PV/T Collector

The energy balance of the developed thermal model is based on the energy transfer phenomenon in the various components of the collector.

5.3.1 Glass Cover

Where G is the strength of the incident solar radiation hit glass cover over 93% solar radiation will transmit to the second medium. But small magnitude of solar energy will have reflected and absorbed by the glass. And those values must be determined for knowing their effect.

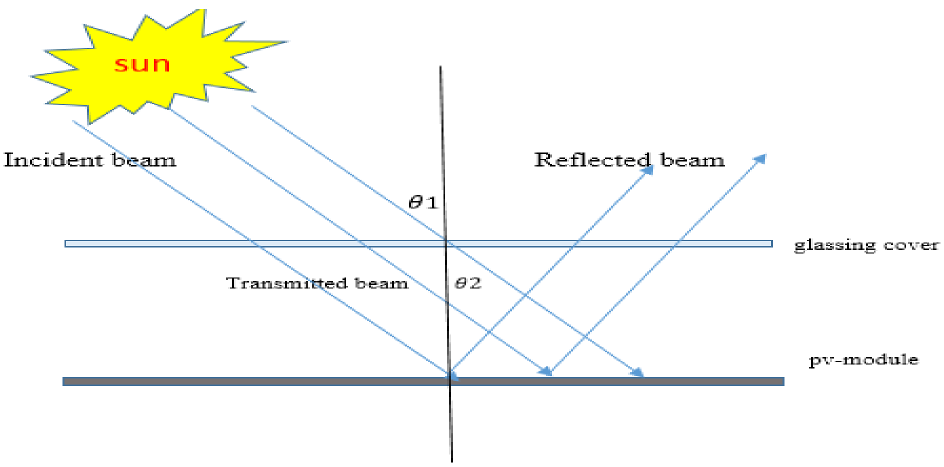

Figure 5.5: Solar Incident on Glass and Reflection

a) Reflection of Radiation

For smooth surfaces the Fresnel expressions calculate the reflection of un polarized radiation on passing from medium 1 with a refractive index n_1 to medium 2 with a refractive index n_2 , **τr** and r are the transmission (due to the reflex ion partial of the incidental radiation) and the reflection coefficients respectively.

$$\tau r = \frac{1-r}{1+r} ------------------- Eq(5.24)$$

$$r = \frac{1}{2}\left[\frac{\sin2(\theta_2-\theta_1)}{\sin2(\theta_2-\theta_1)} + \frac{\tan2(\theta_2-\theta_1)}{\tan2(\theta_2-\theta_1)}\right] ------ Eq(5.25)$$

Where: θ_1 and θ_2 are the angles of incidence and refraction, as shown in Figure 5.2.

b) Absorption by Glazing

The absorption of radiation in a partially transparent medium is described by Bouguer's law, which is based on the assumption that the absorbed radiation is proportional to the local intensity in the medium and the distance the radiation has traveled in the medium. The transmittance of the medium is then the reminder of absorption.

$$\alpha_g = 1 - \tau_g \text{ ------------------ } Eq(5.27)$$

Where: $\tau_V =$ is the transmittance of glass cover determined in the ref

$$\tau_g = e^{-\frac{\lambda \delta v}{\cos\theta 2}} \text{ ------------------- } Eq(5.28)$$

$$\theta_2 = \text{arcsine} = \left(\frac{\sin}{v_n}\theta 1\right) \text{ ------------- } Eq(5.29)$$

With: θ_2 is the refraction angle.v_n is the refraction index of the glass and λ is the extinction coefficient of the glass.

Finally, the transient energy balance on the glass cover will be calculated as function those properties described above and total heat loss coefficient.

$$(mcp)g\frac{\partial Tg}{\partial t} = Ic(\alpha)_g - (h_{1c} + h_{1r}) * (T_g - T_a) + (h_{2c} + h_{2r}) * (T_{pv} - Tg) -- Eq(5.30)$$

Where;

mcp_g is the product of mass of the glass and specific heat of the glass

Ic is estimated total solar radiation which find in solar radiation assessment hourly.

h_{1c} the convective heat transfers coefficients between glass and ambient.

h_{1r} the radiative heat transfers coefficients between glass and ambient

h_{2c} the convective heat transfers coefficients between glass and pv module

h_{2c} the radiative heat transfers coefficients between glass and pv module

T g glass temperature

Ta air temperature

Tpv temperature of the module

The mass of the glass cover determined from δ_g, ρ_g, cp_g and α_g are respectively thickness, mass density, specific heat and absorption of glass cover. Tc, Ta is respectively temperature of sky and temperature of ambient air. h r, g-am, −is radiation heat transfer coefficient between glass cover and sky; hvent is the convective heat transfer coefficients due to the wind.

5.3.2 PV Module

After estimating the solar energy which arrived in the PV module the partial energy converted to electrical and more energy is dissipate as heat and transfers to solar observer. To determine the produced electrical energy and amount transfer heat to the heat observer the coefficient heat transfer from the PV module to the glass are assumed as degraded.

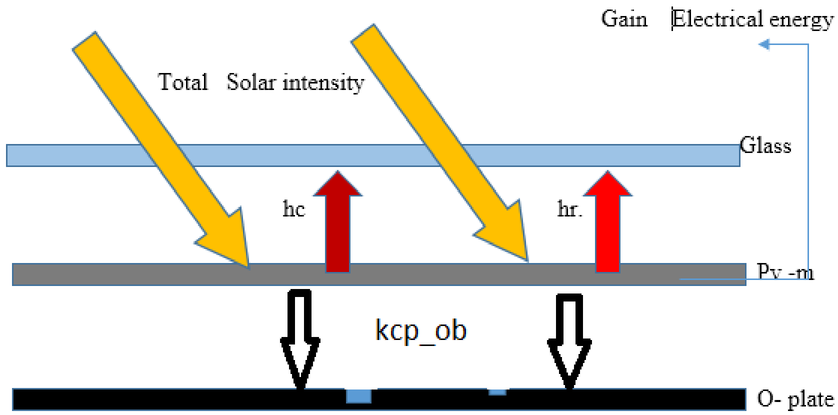

Figure 5.6: Energy Balance on Pv-Module

Then the transient energy balance on the pv-module becomes difference of total solar intensity passed though glass cover minus the gain electrical energy and the loss back to the glass. Mathematically this is expressed as follows

$$(mcp)pv\frac{\partial Tpv}{\partial t} = G(\alpha\tau)pv - E - (kc,_{pvp} * (Tp - Tpv) - Upv_g * (Tpv - Tg) - - Eq(5.31)$$

Where $(mcp)_{pv}$ is determined from δ_{pv} is the thickness of pv and ρ_{pv}, cp_{pv} is the mass density and the specific heat of pv panel respectively. And **(**ατ**)** is the effective absorptance of the PV panel given by the relation below.

$$(\alpha\tau)_{pv} = \frac{\tau_v\tau_r\alpha_{pv}}{1-(1-\alpha p)_r} - - - - - - - - - - - - - - Eq(5.32)$$

The electrical power output E depends on the temperature of the cells T_{pv}; it is calculated by as:

$$E = I_c P\tau_v\eta_o[1 - \varphi_c(T_{pm} - 25)] - - - - - - - - \quad Eq(5.33)$$

Where, η_0 is the electrical conversion efficiency at the reference temperature T_r=25°C. c ϕ is the temperature coefficient of the solar cell with ϕ_c= 0.0045°C^{-1} and P is the packing factor of the cell. The PF is defined as the fraction of the area occupied by the cells to the total module surface area. Where: kc_{pvp} is the conduction heat transfer coefficients in the adhesive layer.

5.3.3 Plate Absorber

The energy balance on the heat observer plate is defined as followed.

$$(mcp)p\frac{\partial Tp}{\partial t} = hcc,p\_pv(Tpv - Tp) + \frac{Ap_t}{At}(hc,p_t * (Tt - Tp) - -Eq(5.34)$$

Where: δ_p, ρ_p, cp_p are respectively thickness, mass density and specific heat of the plate. hc,p_t conduction heat trans for coefficients between plate absorber and tube. And Apt is contact surface between the plate absorber and the tubes, given by the following relation.

$$Ap_t = \frac{\pi}{4} NDeiL ------------ Eq(5.35)$$

With, N is the total number of tubes and De is the external diameter of tubes

5.3.4 Tubes

Tube is the corner stone for the cooling of the system which is highly affect the performance the total output, the electrical as well as the thermal result. The tubes are welded under the heat observer using the high conductor material for better metal to metal heat transfer.

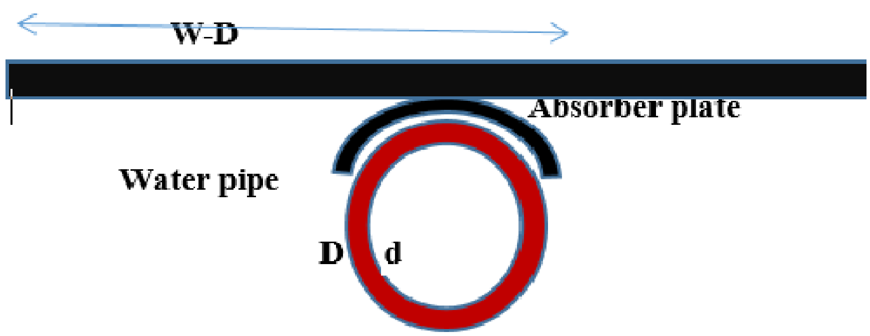

Figure 5.7 The cross section view of water tube

Where: δt, ρt and Cpt are respectively thickness, mass density and specific heat of the tubes. hv,f_t, are the convective heat transfer coefficients between the tubes and the fluid. A_f is the contact surface of tube- fluid given by the relation.

$$Af = NDiL\pi --------------- Eq(5.36)$$

Ai is the insulation surface.

5.3.5 Water Stream

Making an energy balance for the water stream, the temperature of the water leaving the solar collector at any time (τ Δ + t) is determined from data at time t as follows:

$$(mCp)w\left(\frac{dTwo}{dt}\right) = Aw * Uopw * \left\{FwTop - \frac{Two + Twi}{2}\right\} - (\dot{m}cp)w * (Two - Twi) - -Eq(5.37)$$

With $(mcp)w$ stored mass of fluid with Specific heat of the fluid, Up transfer coefficient Convective heat transfer coefficients between the absorber plate and fluid the fluid temperature of the preceding section. A_{if}: the fictitious surface of the fluid flow on insulation with:

$$A_{if} = NDel - ---------------- Eq(5.38)$$

5.4 System Output and Performance Evaluation

5.4.1 The Electrical Model Out-Put

According to concussion of the literature review, the PV generator consists of a collection of solar cells connected either in parallel or series or combination of both depending connecting leads weather it the application needs high voltage or high current. Since our objective is producing energy for the estimated demand it must be determined the actual electrical energy gain for the designed system.

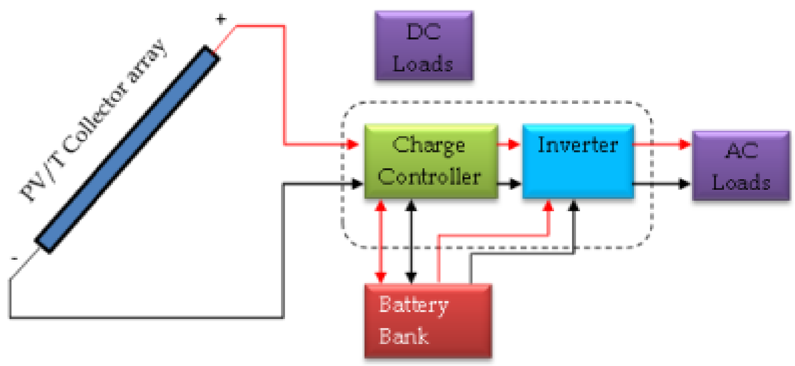

Figure 5.7: Electrical System Model

To do so investigation of all system like all possible electrical resistance has to be considered. The typical PV cell configuration can be represented diagrammatically by. As can be seen, there is a current source Ip, a diode and a series resistor Rs equivalent to internal resistance of the cell. The shunt resistance represents the internal resistance of the diode.

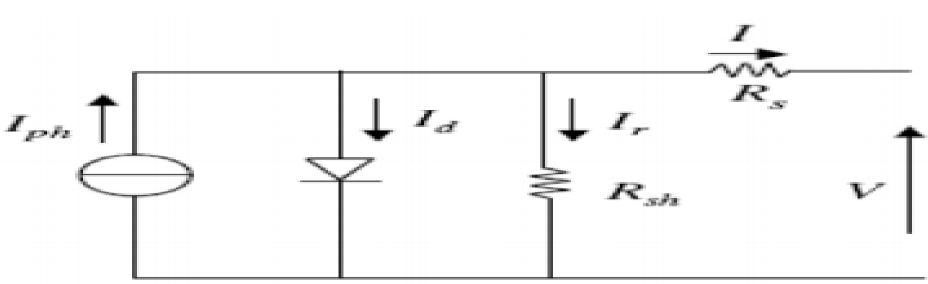

Figure 5.8: Equivalent Circuit of Photovoltaic Cell with Single Diode

The diode current Id is given is;

$$\mathrm{Id} = \mathrm{Io}\left\{\mathrm{exo}\left(\frac{\mathrm{q(V-IRs)}}{\mathrm{n.T.k}}\right)-1\right\}-\frac{\mathrm{(V-IRs)}}{\mathrm{Rsh}} ------ \mathrm{Eq(5.39)}$$

Where Io is the temperature dependent dark saturation current (A); q is the electronic charge (1.602×10^{-19} J/V); Tpc is the cell absolute temperature (K); V is the voltage across the cell and k is the Boltzmann's constant. However, the load resistance is usually much less than the shunt resistance but much bigger than the series resistance, thus the power dissipated within the cell is negligibly small. Therefore, the series and shunt resistances can be ignored then the expression becomes:

$$\mathrm{Id} = \mathrm{Io}\left\{\mathrm{exo}\left(\frac{\mathrm{e(V - IRs)}}{\mathrm{kTpc}}\right) - 1\right\} --------- \mathrm{Eq(5.40)}$$

Where induced current in photovoltaic cell is generated as the photo light is hit cell material and absorbed and this may be expressed as function the given intensity of solar radiation and the operated temperature of system. Mathematically this is written as follow.

$$\mathrm{Iph} = [\mathrm{Iscr} + \mathrm{ki}(\mathrm{T} - \mathrm{Tstc})]\frac{(\mathrm{G})}{\mathrm{Gr}} --------- \mathrm{Eq(5.41)}$$

Where Iscr is given reference initial short current, ki Temperature versus current coefficient (here: 0.0025A/°C), $\mathrm{T} - \mathrm{Tstc}$ is the Temperature difference of the cells and the given reference and $\frac{(\mathrm{G})}{\mathrm{Gr}}$ the ratio of solar radiation intensity.

a) Short Circuit Current (Isc)

The short circuit current Isc corresponds to the short circuit condition when the impedance is low and is calculated when the voltage equals 0. I (at V=0) = Isc. Isc occurs at the beginning of the forward-bias sweep and is the maximum current value in the power quadrant. For an ideal cell, this maximum current value is the total current produced in the solar cell by photon excitation

$$I_{sc} = I_{shint} * \left\{\mathrm{exo}\left(\frac{\mathrm{q.(V)}}{\mathrm{k.Tin.n}}\right) - 1\right\} -------- \mathrm{Eq(5.42)}$$

Where Ishint the leaking currents which is fraction of short circuit current pre Shunt resistance that expressed in many variables but mostly considered as (500 Ohms).whereas the short circuit current is getting from the following formula and in most causes this value is take as 4.75 A for computing purposes.

$$\mathrm{Isc} = \mathrm{Ishint}\left(\left(\frac{\mathrm{T}}{\mathrm{Tinit}}\right)^3 .\exp\left(\frac{\mathrm{q.(Vg)}}{\mathrm{k.Tin.n}} * \left(\frac{1}{\mathrm{T}} - \frac{1}{\mathrm{Tinit}}\right)\right)\right) --- \mathrm{Eq(5.43)}$$

To define the system, the other significant parameter is the voltage of the cell to compute this, it necessarily true to know the value of cell voltage. The cell voltage is highly affected by the operating temperature and the initial value the open circuit voltage.

b) Open Circuit Voltage (Voc)

The open circuit voltage (V_{oc}) occurs when there is no current passing through the cell. V (at I = 0) = V_{oc}.(V_{oc}) is also the maximum voltage difference across the cell for a forward bias sweep in the power quadrant $V_{oc}= V_{max}$ where Isc=0, mathematically this may have expressed as follow

$$Voc = Vocinit * \left(1 - 0.0037 * (T - Tinit)\right) - - - - - - Eq(5.44)$$

Finally, the following equation then describes the entire PV panel where the cell configuration dependently is specific objective of the system.

$$Ipv = np.Iph - np.Irs.[exo\left(\frac{q.}{k.T.A} * \left(\frac{Vpv}{ns}\right) - 1\right) \; - - Eq(5.45)$$

When np, the number of cell connected in parallel and ns, connected in series**,** from for the improved understanding of the PV cell theory, an I-V characteristic curve for a solar cell can be - +V Id, Rs, Rsh, Ip Proceedings of the generated for a given irradiance G and at fixed cell temperature Tpc. When the cell is short circuited, the short circuit current Isc is maximum and the voltage across the cell is zero. While the circuit is open, the voltage Voc is maximum and current is zero look the following I-V curve. In conclusion the net current gained from the system is could be estimated from the Kirchhoff's law is calculated as given below.

$$I = I_{ph} - I_d - I_r - - - - - - - - - - - - - - - - Eq(5.46)$$

c) Maximum Power (Pmax), Current at Pmax (Imp), Voltage at Pmax(Vmp)

The power produced by the cell in Watts can be easily calculated along the VI sweep by the equation P = VI. At the Isc and Voc points, the power will be zero and the maximum value for power occurs between the two. The voltage and current at this maximum power point are denoted as Vmp and Imp respectively. The maximum power dissipated is the product of current and voltage as follows.

$$P_{max} = I_{max}V_{max} - - - - - - - - - - - Eq(5.47)$$

5.4.2 Thermal Model Out-Put

The thermal model is a model which is prepared for utilizing the extra heat from the electrical model. This is basically of the flat-plate solar collector with properly engaged with copper tube to harvest the useful thermal energy and transfer to the heat transport medium fluid water .as it described later in the review this is the basic component in improving the required output as well the system efficiency. The arrangement in Figure is applied for the analysis in this case:

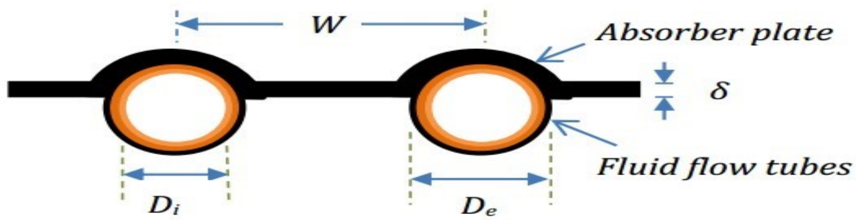

Figure 5.9: Cross Section of the Absorber Plate Fluid Tubes Configuration

a) Collector Efficiency Factor

The collector efficiency factor represents the ratio of the actual useful heat collection rate to the useful heat collection rate when the collector absorber plate (Tp) is at the local fluid temperature (T_f). Figure 5.11 demonstrates the absorber plate-tube configuration of the present collector model. Let W be the distance between the tubes, D is the tube diameter and δ is the sheet thickness as shown below

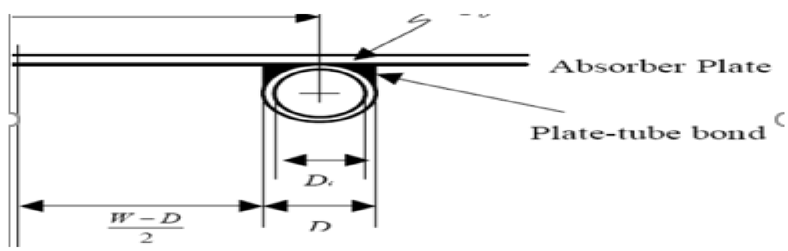

Figure 5.10: Absorber Plate-Tube Configuration

Assume the sheet above the bond to be at some local base temperature Tb. The region between the center line separating the tubes and the tubes base can then be considered as a classical fin problem. Since the sheet material is a good conductor, the temperature gradient through the sheet is insignificant and the heat flow will toward the working fluid which circulates inside the pipe, then it is logical to assume one-dimensional heat transfer. Accordingly $\frac{dq}{dy}, \frac{dq}{dz}$, will be zero and remain constant look the figure below.

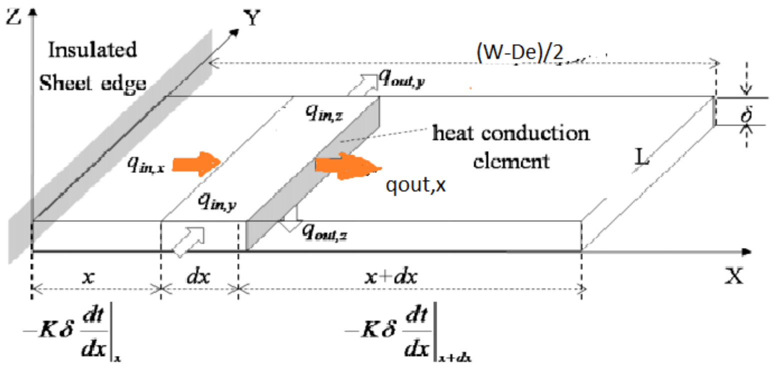

Figure 5.11: Heat Flow Pattern at the Elemental Length 'dx' on the Fin Sheet

For a controlled finite element per unit width, For the transient model following energy conversion equation can be applied

$$m_f Cp\frac{dT}{dT} = Qodso\Delta X - UL\Delta x(Tx - Ta) - k\delta\frac{dT}{dx}\Delta x - \left(-k\delta\frac{d}{dx}(T + dT)\Delta x\right)$$

$$m_f Cp\frac{dT}{dt} = Qobso\Delta x - UL\Delta x(Tx - Ta) + k\delta\frac{d^2T}{dx^2}\Delta x - - - - -Eq(5.48)$$

This equation has two boundary based on the assumption above

$T(0,t) = 0, \frac{\partial T}{\partial x}\left(\frac{W-D}{2}, t\right) = Tb\ , for\ t > 0$.For solving the above equation $Eq(5.48)$ the Fourier mathematical computing is the first alternative.However, since the main objective is determining the collector efficiency factor which is highly dependent on its geometry shape and sizes it is logical to evaluate fin energy balance at steady state condition. Hence the above equation becomes:

$$\frac{d^2T}{dx^2} = -\frac{Qob}{k\delta} + \frac{U_L}{k\delta}(T - Ta) = 0 - - - - - - - - Eq(5.49)$$

$$\frac{d^2T}{dx^2} = \frac{UL}{k\delta}\left(T - Ta - \frac{Qob}{UL}\right) = 0 - - - - - - - - -Eq(5.50)$$

Consider some simplification is make for mathematical manipulation and let as written as below

$$m^2, = \frac{UL}{k\delta}, \psi = \left(T - Ta - \frac{Qob}{UL}\right) - - - - - - - - -Eq(5.51)$$

Then rewrite the equation above,

$$\frac{d^2\psi}{dx^2} - m^2\psi = 0 - - - - - - - - - - - - - - - \quad Eq(5.52)$$

With the boundary condition w.r.t x $\frac{dT}{dx}\Big|_{x=0} = \frac{d\psi}{dx}\Big|_{x=0} = 0$, at $\psi|_{\frac{W-D}{2}} = \left(T_b - Ta - \frac{Qob}{UL}\right)$

The general solution for $Eq(4.50)$ becomes

$$\psi = C_1 \, sinhmx + C_2 coshmx - - - - - - - - Eq(5.53)$$

The constantsC1 and C2 can be found by substituting the boundary conditions into the general solution.

$C_1 = 0, C_2 = (T_b - Ta - Qob/UL)/(cosh\ (W-D)/2)$, then the general solution becomes.

$$\frac{T - Ta - Qob/UL)}{T_b - Ta - Qob/UL)} = \frac{coshmx}{(cosh\ (W-D)/2)} - - - - - - -Eq(5.54)$$

The energy conducted to the region of the tube per unit of length in the flow direction can now be found by evaluating Fourier's law at the fin base.

$$q'fin = -k\delta \frac{dT}{dx} \qquad at\ x = \frac{W-D}{2} - - - - - - - - Eq(5.55)$$

$$q'fin = \frac{k\delta m}{UL}\big(Qob - UL(T_b - T_a)\big)tanh\frac{m(W-D)}{2} - - - Eq(5.56)$$

But $m^2, = \frac{UL}{k\delta}\frac{k\delta m}{UL}$ is just$\frac{1}{m}$, and $Equation$ (4.55)accounts for the energy collected on only one side of a tube. For both sides, the energy collection is

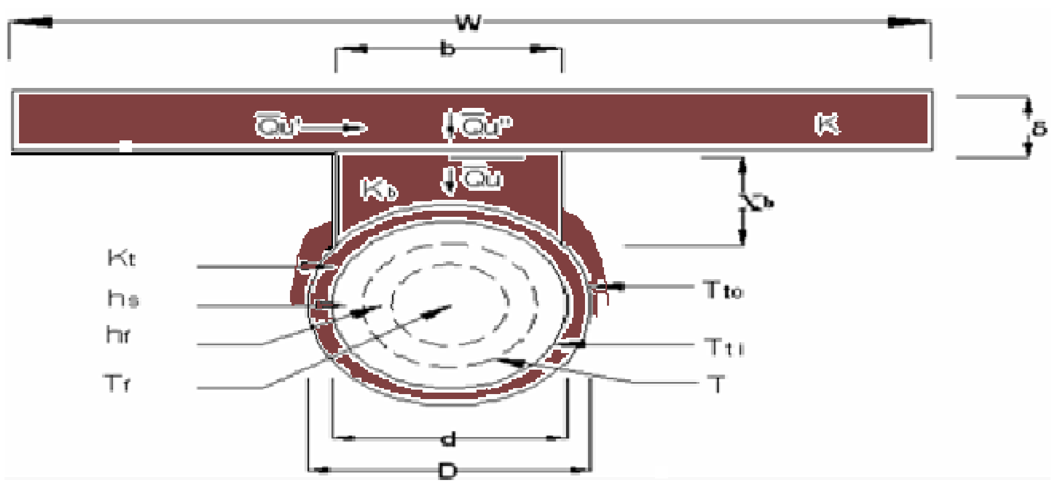

Figure 5.12: Schematic Representation of a Section through a Typical Finned-Tube

$$q'fin = (W-D)\big(Qob - UL(T_b - T_a)\big)\left(\frac{tanh\left(\frac{m(W-D)}{2}\right)}{\frac{m(W-D)}{2}}\right) - - - \quad Eq(5.56)$$

It is convenient to use the to rewrite the above Equation

$$Q'fin = (W-D)F\big(Qob - UL(T_b - T_a)\big) - - - - - - -Eq(5.57)$$

Where the fin efficiency is:

$$F = \left(\frac{\tanh\left(\frac{m(W-D)}{2}\right)}{\frac{m(W-D)}{2}} \right) ------------- Eq(5.58)$$

The resistance to heat flow from the plate to the tube may be consisted of the following components.

- The resistance due to the bonding material between the plate and the tube;
- The resistance due to the temperature gradient in the fluid at absorber plate the tube wall;
- The resistance due to the wall thickness of the tube.

$$\dot{q}u = \frac{\dot{T}b - Tf}{\frac{1}{Cb} + \frac{1}{\pi dhf} + \frac{1}{Cw}} ------------- Eq(5.59)$$

Where

Cb is the conductance of the bond

Cw is the conductance ofthe tube wall

hf is the forced convection heat transfe coefficient inside ofthe tube conductance

Tf is the fluid temprature.

The bond conductance can be calculated as;

$$C_b = \frac{K_b b}{X_b}, Cw = \frac{\pi Amwk_t}{X_t} ------------ Eq(5.60)$$

wher kb, the conductivity ofthe bond xb, the thickness ofthe bond and b the length of the bond $xt = \frac{D-d}{2}$ is the thickness of the tube. The bond conductance is very important in accurately describing collector performance. Simply connecting or clamping of the tubes to the sheet results in a weighty loss of performance. It is necessary to have good metal to metal contact so that the bond resistance is less than 0.03 m ºC /W. The useful energy gains per unit flow length transferred to the flowing fluid can then be expressed in terms of the known dimensions, the physical parameters and the local fluid temperature by Solving the following equation(4.60) for T_b and subsisting to obtainued.

$$\dot{Q}u = WF'[Qabs - UL(Tmp - Ta) - Qe] --------Eq(5.61)$$

F' is called the collector efficiency factor. Physical interpretation of F', for most collector geometries will be clear from equation (4.61). Where W is the separating distance between the central axes of the tubes, the standard fin efficiency, F', which expressed as $ULk\delta WDe\,2$

$$F' = \frac{\frac{1}{Ul}}{W\left\{\frac{1}{UL(De+(W-De)F)} + \frac{1}{Cb} + \frac{1}{Diwm\pi}\right\}} --------Eq(5.62)$$

5.5 Useful Heat Gain

The aggregate heat absorbed by the collector Qu is conventionally expressed as the product of mass flow rate, specific heat capacity of the cooling fluid and the temperature difference of outlet and inlet fluid. The performance of a flat-plate solar collector can be described by the useful gain from the collector per unit time of a collector area Ac and it is the difference between the absorbed solar radiation and the thermal loss or the useful energy output of a collector.

$$\mathrm{Qu} = \dot{m}\mathrm{cp}(\mathrm{Tout} - \mathrm{Tin}) ------------\mathrm{Eq}(5.63)$$

The solar energy received by the PV module is a function of the solar radiation striking the module, the transmittance of the glazing cover and the absorptance of the PV surfaces, which can be given by [19]

$$\mathrm{Q_{abs}} = \tau_g[\alpha_p\beta_p + \alpha_b(1 - \beta p)]\mathrm{AcI} ------\mathrm{Eq}(5.64)$$

Where Qabs the heat absorbed for the pv module, τg, is the visual transmittances of cover glazing layer; αp and αb are the absorption ratios of the PV layer and its baseboard; βp is the packing factor of PV layer; Ac is the collector area of the module (m^2).when this is considered, the expression for the useful energy Qu is given as under the transient-state condition, the rate of useful heat delivered by the module equals the rate of the absorbed energy minus the overall heat loss and converted electricity, which is expressed as;

$$\mathrm{Qu} = \mathrm{Ac}[\mathrm{Qabs} - U_L(\mathrm{Tmp} - \mathrm{Ta}) ----------\mathrm{Eq}(5.65)$$

Where U_L is the overall thermal loss coefficient, Ta and Tmp are ambient air temperatures and mean absorber plate temperatures respectively. The latter is an intricate function that depends on the collector design, solar insolation and working fluid. Therefore, a modified Hottel -Whiller–Bliss thermal efficiency equation comes into play. Since this excludes the heat energy converted into electrical energy Qe as the actual useful heat energy that accumulate in the thermal model will be expressed as minus of the total loss and electrical energy produced.

$$\mathrm{Qu} = \mathrm{Ac}[\mathrm{Qabs} - \mathrm{UL}(\mathrm{Tmp} - \mathrm{Ta}) - \mathrm{Qe}] -----\mathrm{Eq}(5.66)$$

The useful gain of the collector also includes the energy collected above the tube region. The solar energy absorbed just above the tube per unit of length in the flow direction can be calculated by:

$$\dot{Q}tube = D[\dot{Q}abs - UL(Tb - Ta) - Qe] - - - - - - Eq(5.67)$$

Hence, the total energy gains of the collector tubes per unit length in the flow direction may be expressed as:

$$\dot{Q}u = \dot{Q}_{fin} + \dot{Q}_{tube} = [(W - D)^{\eta}f + D\}[\dot{Q}abs - UL(Tb - Ta) - Qe] - Eq(5.68)$$

Eventually, the useful gain from equation $Eq(4.68)$ must be transferred to the fluid.

The system's thermal efficiency factor is a constant figure under the fixed physical and operating condition. However, this factor's value varies in the following ways: it decreases with increasing fin width, increases with increasing material thickness and thermal conductivities, decreases when there is an increase in the overall heat loss coefficient, and increases with decreases in the overall system heat transfer resistance.

5.5.1 Water Temperature Distribution in Flow Direction

In the section 4.3.5 it has been described that the water temperature distribution with respect of hourly solar radiation. But this is not enough to show the temperature of water varies along the tube. Consider the control volume energy balance on a fluid element flowing through a pipe of length Δx, which is receiving a uniform heat flux.

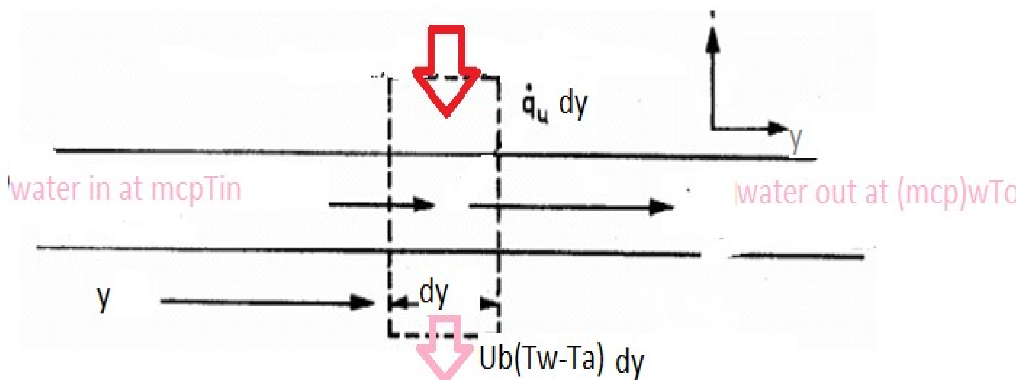

Figure 5.13: Energy Balance on Water Stream

The energy balance for the control volume will be the difference of incoming and out coming energy for the given differential area. Let as assume the second order it considers the temperature of the water is varied along the y-axis with time.

$$\dot{m}Cp\frac{dTf}{dt} = \left[-\frac{\dot{m}}{no}\right]CpTf|y - \left[-\frac{\dot{m}}{no}\right]CpTf|y + dy + \dot{q}u\Delta y - Ub(Tw - TA)\Delta y$$

$$\dot{m}cp\frac{dTf}{dt} = \left[\frac{\dot{m}w}{no}\right]cp\frac{d^{2}Tf}{dy^{2}} + \dot{q}u\Delta y - Ub(Tw - Ta)\Delta y \quad - - - - - Eq(5.69)$$

Where

Cp is the specific heat of the water.

ṁ is the mass flow rate of the water.

Tf is the fluid temprature at the given position.

Ta is the ambiant temprature at the given position.

Ub the overall heat loss Coefficient from tube to ambient trough bottom surface

For solving this equation which depends on two independent variables, numerical computing is preferable than analytical method.

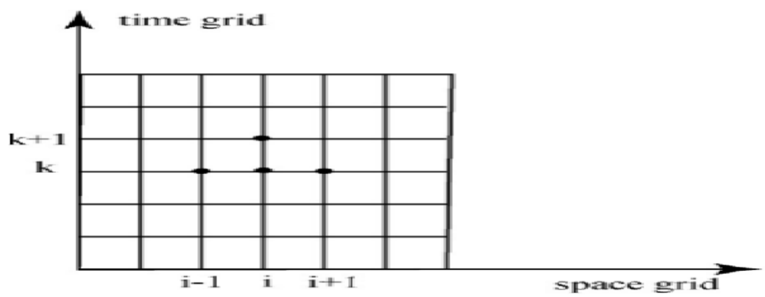

Figure 5.14: Time-Space Grid

$$\dot{m}cp\frac{Tf(i,k+1)-Tf(i,k)}{dt} = \frac{\dot{m}}{n}cp\frac{Tf(i+1,k)-2Tf(i,k)-Tf(i-1,k)}{\Delta y^2}+\dot{q}u\Delta y-Ub(Tw-Ta)\Delta y - Eq(5.70)$$

Where (i, k), represents the nodal representations of the for time space grid.

5.6 Performance Evaluation of the System

a) Overall Energy Efficiency

Overall energy efficiency is the ratio of collected electrical and heat energy to incident solar radiation striking on the PV/T absorber. It is yielded from the first law of thermodynamics and indicates the percentage of the energy converted from the solar radiation. In a PV/T module, the electrical efficiency is much lower than the thermal efficiency and therefore the overall energy efficiency will largely rely on the thermal energy conversation of the system.

$$\text{Electrical efficiency} = \eta_e = \frac{\text{ImVm}}{\text{AcIc}} - - - - - \text{Eq}(5.71)$$

$$\text{Thermal efficiency} = \eta_{th} = \frac{\text{Qu}}{\text{AcIc}} - - - - - \text{Eq}(5.72)$$

To calculate total efficiency of the system it is possible to take the sum their efficacy.

$$Te = \eta_e + \eta_{th} {}_+ = \frac{ImV_m}{AcIc} + \frac{Qu}{AcIc} ------ \; Eq(5.73)$$

However, keep in mind that the overall energy efficiency discounts the difference between heat and electrical energy in terms of the energy quality and therefore, is insufficient to fully rationalize the energy performance of the PV/T systems.

b) **Overall Exergy Efficiency**

Overall exergy efficiency takes into account difference of energy grades between heat and electricity and involves a conversion of low grade thermal energy into the equivalent high grade electrical energy using the theory of Carnot cycle. The overall exergy (Ex_o) of the PV/T could be written as follow:

$$Ex_o = Ex_{th} + Ex_e = (\xi_{th} + \xi_e) * I = \xi_O I \; ---- \; Eq(5.74)$$

Where, Ex_{th} andEx_e and the thermal and electrical exergy respectively which are written as

$$Ex_{th} = \eta_c Qu = \eta_c \, \eta_{th} I = \xi_{th} I and Ex_e = \eta_e I = (\xi_e I) --- \; Eq(5.75)$$

$(\xi_{th} + \xi_{e})$ the thermal and electrical exergy efficiency. And the total overall exergy efficiency becomes

$$\xi_O = \eta_c \, \eta_{th} + \eta_e ------------- Eq(5.76)$$

Where η_c the ideal Carnot efficiency is estimated from 0.32-0.4

c) The Primary-Energy Saving Efficiency

Huang was suggested another performance evaluation method to recognize the energy grade difference between heat and electricity namely, the Primary Energy Saving Efficiency (Ef), which is given by:

$$Ef = \frac{\eta_e}{\eta_{power} + \eta_{th}} ------------ \; Eq(5.77)$$

where, $\eta_{power}$is the electrical power generation efficiency for a conventional power plant which is considered 0.4.

CHAPTER SIX

6. SIMULATION AND OPTIMIZATION OF PV/T

6.1 Significant of Simulation

Simulation is the crucial part in design and analysis of many engineering systems. In parallel to this the thematic idea of heat transfers and fluid mechanics have many variables that affect for any given system directly and indirectly. Since this thesis is made-up from the above two theory's computer simulation is not only necessary but also compulsory. To do this true it needs some commercial software which has recognition on their trustworthiness and reliability. Thus it basically considers the achievement of the specific objectives that has been set as the main goal of the thesis.

In fact, lot of put on have been showed that the significant of simulation software on design and analysis of water based photovoltaic-thermal system and they get effective illustrative method for their outcome and result and few them are used as good reference for this thesis. S.A. Kalogirou, use TRNSYS for modeling and simulation of the hybrid PV–thermal. The method used for the MATLAB analysis of the photovoltaic-thermal panels is typically referred to as the Hottel-Whillier.

6.1.1 Simulation Approach

According estimation of the energy demand and assessment the availability of solar radiation in chapter three and the conceptual design and mathematical transient model of the system chapter four, MATLAB program was developed using those existing equations for each necessary input for the simulation of the model of a photovoltaic-thermal panel, and was used each material properties of the components to calculate and calibrate PVT panel per unit area. For making the work out easy and simple it is good alternative to devolved algorism for summarizing be compacted the process.

6.2 Algorithm for the Transient Model Progress

An initial considerable guesses at (t = 0) from the module cover to the water in the tank is desired before starting the iteration. The corresponding initial and boundary conditions, i.e., component temperature, initial ambient temperature, wind speed and water temperature, were obtained from the literature review and metrological records.

i. Assign the basic system design and operating parameters into code.

ii. Input the external boundary conditions

iii. Assume the initial parameters' values, Tg^0, Tpv^0, Tob^0, Tw^0, Tsw^0, mr0.

iv. Set up the time step size, Δt, and space step size, Δx, and start the calculation.

v. Establish the ODE system by carrying out heat analysis on each module/system component and rewriting them in the required format of the "ode15s" solver.

For a single time, the system energy balance can be determined by the integration of the following equations.

a) Analyze the heat balance on the glazing conversing equation during which the cover surface temperature $Tg^{t+\Delta t}$ and PV lamination temperature $Tpv^{t+\Delta t}$ are treated as variables.

b) Analyze the heat balance in PV lamination equations to during which the cover surface temperature $Tg^{t+\Delta t}$, PV lamination temperature $Tpv^{t+\Delta t}$,

c) Analyze the heat balance on the solar absorber using equations to, during which the PV temperature $Tpv^{t+\Delta t}$.$Tw^{t+\Delta t}$ are treated as variables.

d) If (Qth – Qu) / Qth< -0.1% (error allowance), then decrease tp by 0.1 ^{0}C and return to step (iii) for re-calculation;

e) If (Qu – Qe) / Qu< -0.1% (error allowance), then decrease mr by 0.001 kg/s and return to step (iii) for re-calculation.

The procedure is presented in a flow diagram as follow:

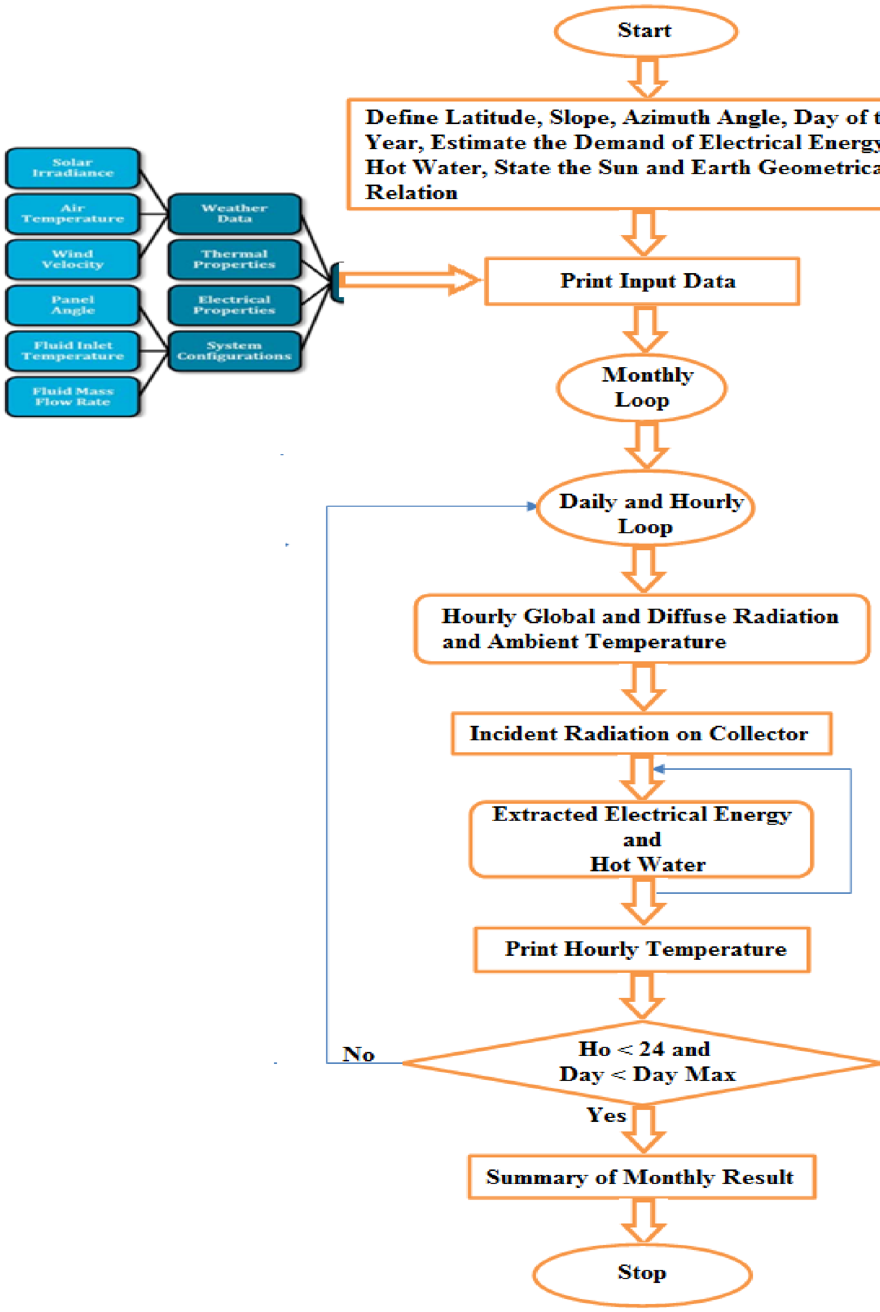

Figure 6.1: Flow Chart of Simulation Procedure

6.3 Optimization of PV/T Design

As we have seen from chapter three and four the design and analysis PV/T need some lot independent and dependent variables. Then those variables especially dependent variables must be optimized from their minimum to maximum value for getting benchmarked point to generates electricity and heat energy through thermal and optical energy conversion. For instance, even there are no energy losses; the input (solar energy) is proportional to the output (electricity). However, due to different factors, which are non-design variables, and controlled factors, which include design variables, the output is reduced. Therefore, the output is lower than the theoretical value because of energy losses. The amount of solar energy, known as solar radiation, is reliant upon the motion of the earth around the sun, the motion of the earth around its own axis, and the angle between the earth's equator and the plane of the sun-earth orbital system. The major concerns for optimization of PV/T solar energy systems are identified as the maximization the output electrical power, heat energy and minimization the total cost. To do this investigation understanding property of many parameters are that highly affect the given system is the basic concept.

It is well known that main concern in a PV/T system is to collect solar radiation by the PV collectors and extract the extra heat that accumulate in the system and causes to decrease the efficiency. Thus, the maximizations of annual monthly average incident solar energy and average incident solar energy for the lowest and highest months are determined by the design of solar PV collector.

PV/T systems should be instantaneously optimized based on the conversion efficiency of system, power output of panels, maximized collection of solar energy by an array system, and minimization costs, including the entire solar PV system and thermal collector, through optimization techniques. Focused on two absorbers types, characterized by different designs: a serpentine tube absorber and a parallel tubes absorber. Starting from the thermal analysis, alternative electrical configurations were simulated in order to define the best solution to maximize as much as possible the photovoltaic performance.

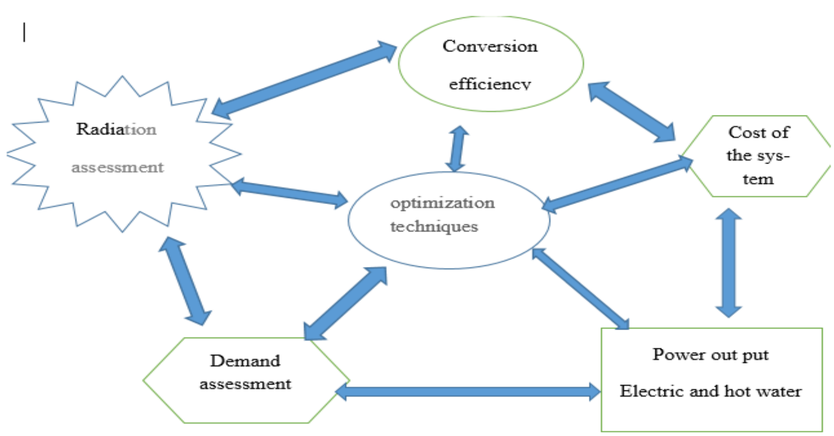

Figure 6.2: The integration of optimization

At the PV module level, the conversion efficiency depends on many factors: material, cell structure, incident light and contact design. At the panel level, the main concern is how to connect individual solar cells and assemble the components. The study focuses on the optimal thermal and electrical configuration of hybrid Photovoltaic-Thermal (PVT) collectors. The electrical production of a PVT system is, in fact, highly affected by the temperature of the PV cells. In a PVT collector a temperature gradient exists along the absorber, so not all cells may be able to operate with the same electrical characteristics due to their temperature coefficient. Formulation of Optimization Problems

In the optimization process it is necessary that, first determine the objective and formulating the optimization problem to be improve the thematic area of the research and to make conclusion about the degree of affectivity for the given variable. Based on this hypnosis two optimization problems are formulated for the optimization of the water based hybrid PV/T system. The first optimization problem is to maximize the variable that has positive impact on the increasing efficiency of the system, in contrary the second optimization problem is minimizes value of the variables that has negative impact on efficiency the given system. Those variables may be value of design parameters such as material properties, geometry of the components collector, location of the site, orientation angle, and operational conditions like seasonal condition, operating temperature of the system, mass flow rate of coolant.

$$\text{maximize } f(\overrightarrow{x}) = \eta_{over} = f(x_1, x_2, x_3, \dots, x_n)$$

6.4 Determine the Parameters Critically Affect Performance the System

Few techniques are used to enhance the performance of PV/T water system. These techniques can be classified in terms of design, such as the physical parameter of the PV/T and the operating condition of the system and environment. In this paper, several parameters that affect the performance of PV/T water system are identified as follow.

a) Tilt Angle of the PV/T

Since the fiat plate solar collectors are positioned at an angle to the horizontal, it is necessary to calculate the optimum tilt angle which maximizes the amount of collected energy. The optimum tilt (inclination) of solar collector with respect to user is an important subject from application of thermal / electrical energy point of view. By utilizing maximum solar energy through the optimum tilt, we are able to harness the energy needed without changing the area of PV/T collector.

Optimum tilt can be achieved by use of tracking systems. There are two types of tracking systems, Manual and Automatic (Programmed). Manual and automatic both tracking systems can be used but automatic tracking system will be expensive and make the system complex as compared to manual one. It is generally known that in the northern hemisphere, the optimum collector orientation is south facing (γ= 0) and the optimum tilt depends upon the latitude and the day of the year. In winter months, the optimum tilt is greater (usually latitude + 15°), whilst in summer months, the optimum tilt is less (usually latitude-15°). There are many papers in the literature which make different recommendations for the optimum tilt, based only on the latitude [2, 3]. In practice, the collector plate is usually oriented south facing and at a fixed tilt which is set to maximize the average energy collected over a year.

Chiou and El-Naggar gave a method to calculate the optimum tilt angle of an equator-facing collector in the heating seasons. Kern and Harris calculated the optimum tilt angle for equator-facing collectors, based on only beam radiation. E1-Sayed has carried out an analysis to determine the optimum tilt angle by considering the effects of the latitude, number of glass covers, clearing index and the solar reflectivity. [13, 14, 15]

Liu and Jordan have suggested that Rb can be estimated by assuming that it has the value which would be obtained if there were no atmosphere. For surfaces in the northern hemisphere, sloped towards the equator, the equation for Rb is given as below and is used in the present study as follow. [7]

$$Rb = \frac{\cos(\phi-\beta)\cos\delta\sin\omega s + \omega s\sin(\phi-\beta)\sin\delta}{\cos\phi\cos\delta\sin\omega s + \omega s\sin\phi\sin\delta} ------ Eq(6.1)$$

where the angles are defined as section 2.1.2 from Matlab manipulation it clearly shown that the above formulae to calculate the monthly average daily total radiation on a surface facing towards equator as the tilt angle is changed from 0 to 90°.

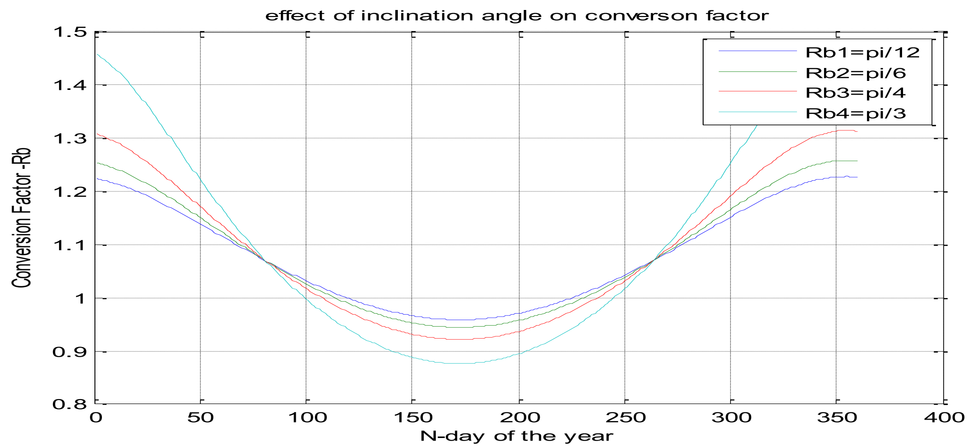

Figure 6.3: Effect of Inclination Angle on the Conversion Factor

As observed from the figure above the value of conversion factor is highly depended on the day of the year. And R_b has great value for inclination angle ($\beta=60^0$) from January up to February half and from around September ten to end of the year. For the rest of day of the year the collector must be tilted at the inclination angle ($\beta=15^0$).

b) Glass Cover

Glass cover is one the component in the PV/T which has significant role, starting from its emissivity, air gap between glass and pv module. See the figure below

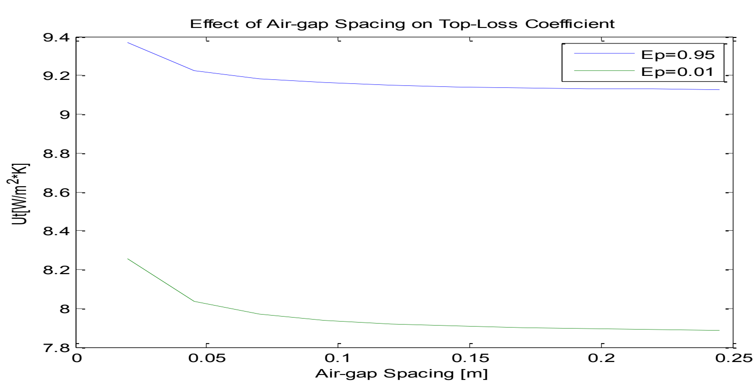

Figure 6.4: Effect of Air Gap and Emissivity Spacing on Top Loss

However, those parameters are good impact in thermal efficiency, Zondag. Reported that PV/T single-cover sheet and tube is suitable for domestic hot water because of its. According to his increasing thermal efficiency has significantly decrease electrical efficiency. Also Dupeyratet al. proposed the use of anti-reflection, coat for glass cover, with a transmission coefficient of the low value 0.94

Additionally, numbers of glass cover increase significant thermal efficiency by decreasing the top Losses as the number of glasses increases from 1 to 2 and at less emissivity. Look the graph top losses as function plate temperature and number of the glass.

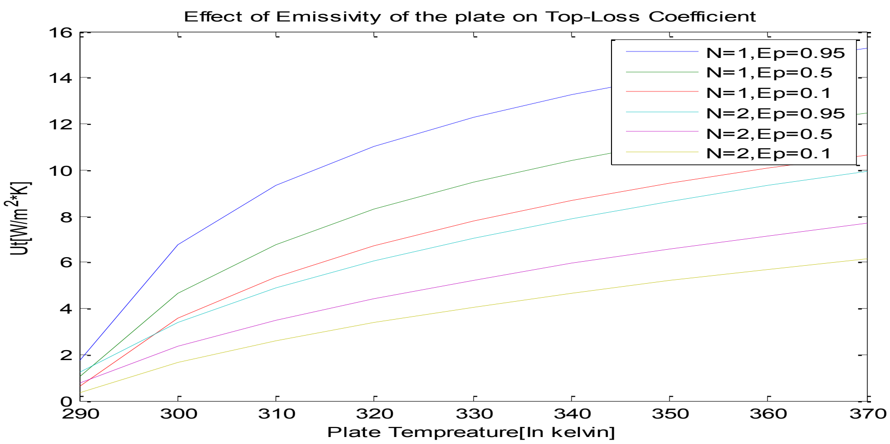

Figure 6.5: Effect of Number of Glass and Emissivity Spacing on Top Loss

c) Effect of Photovoltaic Cell Connection Type of PV Module on Electrical Power

The main difference among series and parallel connection is the values of voltage and current obtained and the related losses due to the temperature coefficients on the voltage and current of the PV cell. In particular,

d) Effect of Operating Temperature of PV Module on Electrical Power

This is the mina variable of the system which has crucial effect on the electrical output, as we remember the main objective of developing the PV/T technology is to minimize the operational temperature of the PV module as much as possible. In the literature review of this paper it is quoted by different scholars that the efficiency of electrical output of the system is decreased (0.1-.0.4) % per unit temperature in degree centigrade. And this manipulated using the Matlab technical computing in this paper according deferential equation and essential electrical module equation.

e) Reducing Thermal Resistance between PV Modules and Thermal Absorbers

The most common method of fabricating a PV/T module is to glue commercial PV lamination to a thermal absorber. This will normally lead to high thermal resistance between the PV module and the thermal absorber due to the nonconductive Tedlar-Polyester-Tedlar (TPT) baseboard, which will thus reduce the overall PV/T performance. In comparison with a conventional TPT baseboard, a treated aluminum-alloy (Al-alloy) sheet can be considered an ideal replacement for integration with PV cells, as it has the advantages of much higher thermal conductivity (144 W/m-K versus

0.648 W/m-K), higher solar absorptance (5% versus 2%), lower solar transmittance (0.2% versus 12.8%) and lower reflectance of solar beams in the wavelengths of 340-1100nm [2.97]. In this thesis, an Al-alloy sheet was utilized for the PV baseboard to accelerate heat transfer at the back of the PV cells.

f) Mass Flow Rate

The mass flow rate is one of the important operating parameters in running the PV/T. The mass flow rate should be sufficient enough be to absorb the heat on the collector. Cristofari [4]. studied the thermal behavior of PV/T in low flow rates 0.007 kg/s. They claimed that the thermal performance for determining the performance of PV/T water system copolymer PV/T design was 55.5% and the electrical 12.7%. The total efficiency was 68.2%. In addition, the uniformity of the mass flow affects the PV efficiency of the PV/T collector system. Ghani conducted about 100 simulations with various designs, geometry shapes (aspect ratio) and operational parameters (mass flow rate and flow directions). They found that the performance for the most uniform flow increased by 9% efficiency, whereas improper mass flow, rate only improved by 2%. To obtain optimum flow they suggested that the manifold-to-riser ratio should be in the range of 4:1 to 6:1 and the aspect ratio of array must be greater than 0.44 to obtain good flow electric yield.

g) Fin Performance

The fin performance is a crucial factor in achieving high efficiency of PV/T water system The fin is also known as the gap of tubes arranged equally through the panel width and bond the absorber plate The bond conduction (C_b) important for metal-to-metal contacts in obtaining low resistance values. Bergene and Lovvik proposed fin configurations the PV/T collector system. Based on their algorithm predictions, thermal efficiency is about halved when the ratio of fin width-to-diameter is ($WD^{\wedge-1}$) increased range of 1 to10 with constant width Reducing space of tube improved the PV/T water efficiency but resulted in cost increase

CHAPTER SEVEN

7. DESIGN OF STORAGE TANK AND SELECTION OF AUXILIARY COMPONENTS

7.1 Theoretical Background

The system beneath is a "Thermal energy storage" (TES) involving in the temporary storage of hot water for later use. The hot water for TES systems be produced water based hybrid photovoltaic solar thermal which investigate in the last chapters of this paper.

Whenever the hot water is provided, the storage tank is essential because it can solve the mismatch between the heat supply and the heat demand. This mismatch arises because the solar radiation changes during the operation leading to a change of the heat supplied that will be realistically unavailable during periods in which it is required, as night or cloudy days, but it may be supplied from the tank previously filled. The key component of the TES system is the storage tank and the processes in which the tank is subjected are as follows:

- The charging phase in which the tank is filled with hot water.
- The storing mode in which the hot water is stored for the future use.
- The discharging phase in which the hot water is taken from the tank.

Based on the operating conditions chosen for charging and discharging phases and depending on the configuration of the tank, ideally, Uniform temperature of the water in the whole volume of the tank: "Fully mixed tank". Researches has appraised and shaped conclusion in different times. For example, Rosen compared a fully mixed and a stratified storage tank configurations using the exergy content of the fluid stored. [22].

7.2 Determination of Storage Tank Volume and Thickness

7.2.1 Volume of Storage

In the estimation of domestic hot water consumption, it has been calculated for middle Ethiopian household around 300 litter and this the base for design the geometry the storage tank.

$$Vo = \pi {r_i}^2 h$$

Where:

$Vo = the volume of the\ tank.$

r_i = is the internal radius of the tank.

h = is the height of the volume.

The volume in litter is changed in meter cube 0.3 m^3

$$Vo = \pi \frac{Di^2}{4} H ------------------ Eq(7.1)$$

For assumption H = 2Di

$$Vo = \pi \frac{Di^3}{2} ------------------ Eq(7.2)$$

Substituting the volume of the tank

$$0.3 * 2 = \pi Di^3$$

$$\sqrt[3]{0.19} = Di$$

$$\underline{\underline{Di = 0.57m}}$$

And the height of the storage will be

$$\underline{\underline{H = 1.14m}}$$

7.2.2 Thickness of the Storage

To estimate the numerical value of those factors firstly it is important to know the thickness of the storage tank. Among of the factors two of them are:

- Heat exchange with the environment
- Axial wall conduction

Of course it is well known that the material it used is an excellent insulator with considering cost per benefit measurement. But the first parameter to optimize the thickness of the storage tank is the magnitude of overall heat transfer coefficient between the storage tank and environment. Considering the first objective of is minimizing loss and let us take the heat transfer is calculated as follow. For combined conduction and convection is given by a cylinder exposed to a flowing fluid look the figure 7.1. For the cylinder the heat flux at the outer surface is given by following equation.

$$\dot{q} = \frac{\dot{Q}}{A} = ho(Tw - T\infty) \ \ at\, r = r_2 -------- Eq(7.3)$$

The boundary condition at the inner surface could either be a heat flux condition or a temperature specification; Thus, at $T = T1, r = r_1$. This is a model for the heat transfer in a pipe of radius r_1

surrounded by insulation of thickness r_2- r1. From the McLaurin series expansion, the solution for a cylindrical region

$$T(r) = a\ ln\frac{r}{r_1} + b \text{ --------------- } Eq(7.4)$$

From the boundary conditions, T(r1) = T1 yields b = T1. At the interface between the cylinder and the fluid, r = r2, the temperature and the heat flow are Continuous.

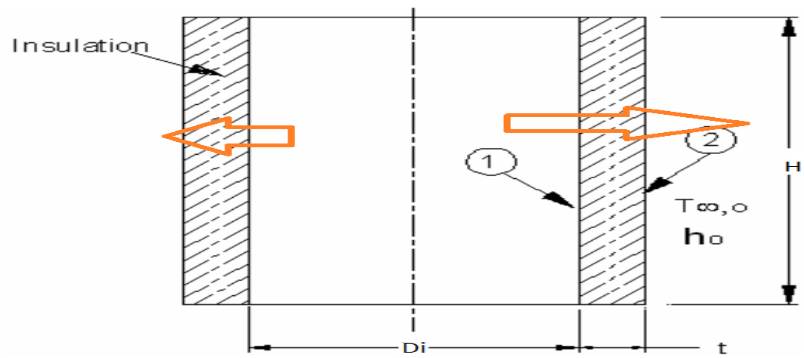

Figure 7.1: The Cross Sectional View of Storage Tank

$$\dot{q} = -k\frac{dT}{dr} = -k\frac{a}{r2} = h\left[\left(aln\frac{r2}{r1} + T1\right) - T\infty\right] \text{ ------ } Eq(7.5)$$

From equation 7.3 solving for constant value (a):

$$a = -\frac{T_1 - T_\infty}{\frac{K}{hr_2} + ln\frac{r2}{r1}}$$

And the expression for the temperature is, in normalized non-dimensional form

$$\frac{T_1 - T}{T_1 - T_\infty} = \frac{ln\frac{r}{r1}}{\frac{K}{hr_2} + ln\frac{r2}{r1}} \text{ --------- } Eq(7.6)$$

The heat flow per unit length is calculated by

$$Q_{loss} = \frac{2\pi(T_1 - T_\infty)k}{\frac{k}{hr2} + ln\frac{r2}{r1}} \text{ ----------- } Eq(7.7)$$

Where:

T_1 is hot water temperature in the storage tank

T_∞, is ambient air temperature.

r_2 is eternal radius of the storage tank.

r_1 inner radius of the storage tank.

h is convective heat transfer coefficient of the ambient.

k is the conductivity of the insulation material.

The problematic interest is selecting the thickness of insulation to reduce the heat loss for a fixed temperature difference $T_1 - T_\infty$ between the inside of the pipe and the flowing fluid far away from the pipe. ($T_1 - T_\infty$ is the driving temperature distribution for the pipe). To understand the behavior of the heat transfer we examine the denominator in Equation (7.6) as r_2 varies. The thickness of insulation that gives maximum heat transfer is given by:

$$\frac{d}{dr2}\left(\frac{k}{hr2} + ln\frac{r2}{r1}\right) = 0 ---------- Eq(7.8)$$

Taking solution of r_2 from the equation 2.24 which gives $r_2 = \frac{k}{h}$

If r_2 is less than this, heat loss increase and it recommended adding insulation. However, the insulation needs some necessarily calculation with respect materiel cost and the amount of saving lost energy. This is done as optimization of the insulation thickness and let as consider the insulation material is selected fiberglass which has good insulation property and tolerable cost.

To determine the minimum thickness of the insulation let us take currently market cost fiber glass and cost of thermal energy.

$$cost\ insulation = 50\ birr * total\ length\ per\ unit\ area$$

$$cost\ heat\ loss = total\ heat\ loss * 0.75\ brir\ pre\ kwh$$

For simple manipulation let as consider the total heat loss as by considering constant convective heat transfer coefficient inside the thermal storage and outside in the ambient temperature.

$$Total\ heat\ loss = \frac{Chang\ of\ temprature}{Equivalent\ resistance}$$

Where the equivalent resistance is determined from the following formula

$$Eq\ resistance = \frac{1}{hoAo} + \frac{loge(R2/R1)}{2\pi LK1} + \frac{loge(R3/R2)}{2\pi LK1} + \frac{1}{hiAi} - -Eq(7.9\ )$$

Where:

ho is ambient convective heat transfer coefficient

hi is convective heat transfer coefficient inside the storage

Ao, Ai is the inside and outside area of thermal storage.

$R1, R2, R3$ are the different radial point of storage.

L is the length or height of the thermal storage.

K1, K2 is the thermal conductivity of the stainless steel and fiber glass insulation. Based on this assumption it has manipulation developed to estimates the desired insulation thickness.

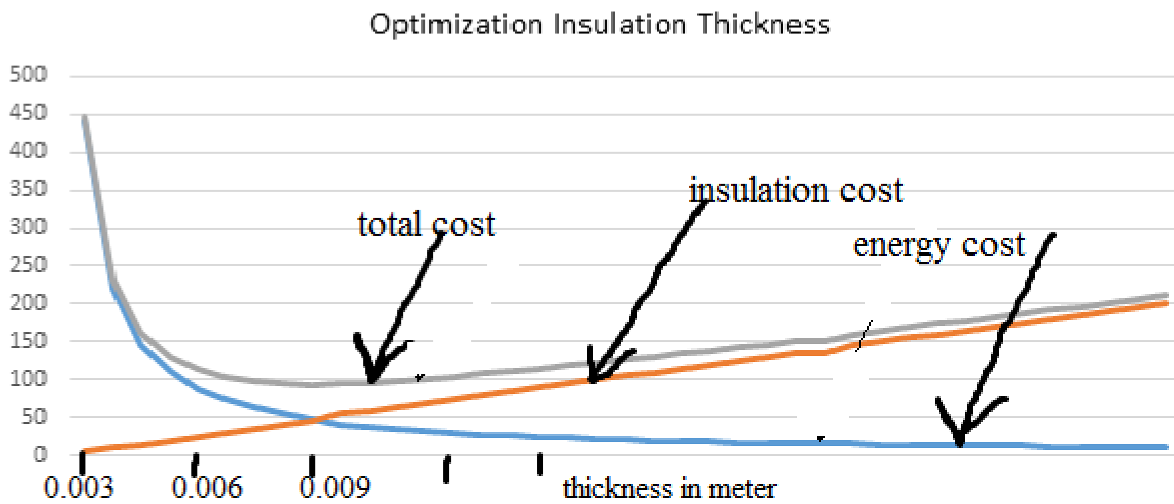

Figure 7.2: Optimization of Insulation Thickness

To understand easily this occurs, consider Figure total cost has minimum value at the point of thickness 9mm for the fiber glass, increasing the thickens of the insulation has great negative impact from the economical point of the thermal storage.

7.3 Energy in Storage Tank and Supply Temperature

The heat balance in the storage tank for the model shown in the figure is given by the following expression:

$$\rho V C_{Pw} \frac{dTs}{dt} = \dot{Q}u - \dot{Q}loss - \dot{Q}load ------ Eq(7.10)$$

Where the left-hand side term corresponds to the heat energy stored in the tank with ρs the given density of the hot water at the given temperature andVS is the volume of the hot water storage and the three terms on the right-hand side of the above expression represent the rate of the net solar energy gain, the rate of heat loss from the storage tank and the rate of heating Load required respectively.

Where the useful energy is estimated as function mass flow rate of the water and temperature difference

$$\dot{Q}u = \dot{m}cp(Two - Twi) ---------- Eq(7.11)$$

Where the loss energy is estimated as function storage surface, loss heat transfer coefficient and the water and temperature difference between the hot water in the storage and ambient.

$$\dot{Q}_{loss} = A_s U_L (Ts - Ta) ---------- Eq(7.12)$$

Where:

As is the storage tank heat transfer area,

UL is the heat transfer coefficient of the storage tank.

Finally, the load energy is estimated as follow

$$\dot{Q}_{load} = A_{Load}(Ts - Tws) ------------ Eq(7.13)$$

$$ALoad = (\rho cp)_W DWC * FF(ii) ----------- Eq(7.14)$$

DWC is the total daily hot water consumption. FF(ii) is the fraction of daily hot water consumption. T_{ws} is the temperature of supply water. Finally equation Eq(7.10) becomes as follows

$$(\rho VC_{Pw})\frac{dTs}{dt} = \dot{m}Cp(Two - Twi) - AsUL(Ts - Ta) - (\rho cp)wWDs * FF(ii)(Ts - Tws) \\ --Eq(7.15)$$

Taking the initial gasses and considering loss from collector to the storage is negligible ($Two = Tso$) and the total loss heat transfer coefficient between storage and ambient is not significantly changed which is calculated at fixed average temperature. Then the change of time with solar hour, the temperature of the hot water at any time in storage tank is estimated as given below

$$Ts = \frac{\Delta t}{\rho VC_{Pw}} * \{\dot{m}Cp(Two - Twi) - AsU_L(Tso - Ta) - (\rho cp)wWDC * FF(ii)(Tso - Tws)\} \\ + Tso ------------------ Eq(7.16)$$

7.4 Selection of Auxiliary Components

7.4.1 Selection of Pump

Pump is one of the main auxiliary components in the given design, since it has advantage to maintain the total head of the system and to control the operation conditions for different solar radiation as well as different outlet temperature of the hot water. But selection of the right pump for system is not simple task, it needs estimating some basic significant parameters that dominates the Performance of the pump. Those parameters many be classified from different aspect but most of the time pump selection is based on.

i. Total head (H) of the system.

ii. The required flow rate.

a) Total Head (H) of the System

This is including pressure drop along each components of the system. Mainly in:

- Pressure drop in the collector.
- Pressure drop in supply and return the pipe.
- Pressure drop in the manifold.
- Pressure drop in the bend.
- Pressure drop due to elevation and inclination of collector.

Assume that the flow is uniform in riser and with length.

A) Pressure Drop in the Collector

In the collector it has the following pressure drop opportunities.

h) Drop in the Riser

The pressure drop in the risers is depending on the geometry of the riser.

$$\Delta \mathrm{Pr} = f * \frac{L}{d} * \rho * \frac{(Vaver)^2}{2} -------------- Eq(7.17)$$

Where:

f is the friction factor of the flow. For laminar flow $f = \frac{64}{Re}$

L is length of the riser.

$d$is the internal diameter of the riser.

ρ is the average of the hot water in the given temperature

$Vaver$the average velocity of the fluid flow

From $\dot{Q} = \rho * Ar * Vave$

Assume that the risers are designed for maximum temperature of the water and take as the pressure drop is happed in the situation and takethe properties hot water at $45^{0}c$

ρ=991 kg/m^3 and μ = 6.87*10^{-4}kg/m^3.Taking the mass flow rate $\dot{m}$=0.002kg/s

Volume flow rate

$$\dot{Q} = \frac{\dot{m}}{\rho} = \frac{2 * 10^{-2}}{991}\frac{m^3}{s}$$

$\underline{\dot{Q}=2.018*10^{-6} m^3/s}$

Where the number of riser per unit meter is 8 and the volume flow per unit riser will be

$$\underline{\dot{Q} = 2.5125 * 10^{-7} m^3/s}$$

Considering the average velocity of the flow from the area of the riser with internal diameter 16mm

$$Vaver = \frac{\dot{Q}}{Ar} = \frac{2.5 * 10^{-7}}{2.* 10^{-4}}$$

$$\underline{Vaver = 0.00065 m/s}$$

Based on this finding the type flow from the equation of Reynolds number which is determined as

$$Re = \frac{Vaver * \rho * d}{\mu}$$

$$Re = \frac{0.00065 * 991 * 0.016}{6.87 * 10^{-4}}$$

$$Re = 150$$

Once the type flow is determined which is laminar the friction coefficient will be calculated as follow

$$f = \frac{64}{Re}$$

$$\underline{f = 0.425}$$

Finally, the pressure drop in unit riser will be calculated from the equation 7.17

$$\Delta Pr = 0.425 * \frac{1 * 991 * ((0.00065))^2}{0.016 * 2}$$

$$\underline{\underline{\Delta Pr = 0.556\ Pa}}$$

For 8 risers per unit area the total pressure drop the riser will be

$$\underline{\underline{\Delta Prt = 4.449\ Pa}}$$

ii) Drop in the Header

Assumption of uniform flow in the header and with L length:

$$\Delta \mathrm{Ph} = f * \frac{L_h}{D} * \rho * \frac{(Vhaver)^2}{2} ----------- Eq(7.18)$$

Where:

L_h is length of the header.

D is the internal diameter of the header.

ρ is the average of the water in the given temperature.

$Vhaver$ is the average velocity of the fluid flow in the header

Since the header is the symmetric the pressure drop will be two times factor.

Volume flow rate

$$\dot{Q} = \frac{\dot{m}}{\rho} = \frac{2 * 10^{-3}}{991}\frac{m^3}{s}$$

$\dot{Q}$=2.018*10^{-6}m^3/s

Considering the average velocity of the flow from the area of the header with internal diameter 26mm

$$Vaveh = \frac{\dot{Q}}{A_h} = \frac{2.018 * 10^{-6}}{5.3066 * 10^{-4}}$$

$\underline{Vaveh = 0.0038}$m/s

Based on this finding the type flow from the equation of Reynolds number which is determined as

$$Re = \frac{Vaveh * \rho * d}{\mu}$$

$$Re = \frac{0.0038 * 998 * 0.026}{6.87 * 10^{-4}}$$

$\underline{Re = 143.526}$

Once the type flow is determined which is laminar the friction coefficient will be calculated as follow

$$f = \frac{64}{Re},$$

$\underline{f = 0.0445}$

Finally, the pressure drop in unit riser will be calculated from the equation 7.17

$$\Delta Ph = 0.0445 * \frac{1.1 * 998 * ((0.0038))^2}{0.026 * 2}$$

$\underline{\Delta Ph = 0.3554\ Pa}$

Since the header is symmetric per unit area the total pressure drop the header will be

$\underline{\Delta Ph = 0.7115\ Pa}$

iii) Drop in the Fitting

The pressure dropping the fitting is calculated as:

$$\Delta \mathrm{Pf} = kf * \rho * \frac{(Vf)^2}{2} -------------- Eq(7.19)$$

Where:kf = Pressure loss factor mostly taken as 0.9.

Vf = average velocity in the tube in the upstream of the fitting. Assume that the flow velocity in the fitting is taken as velocity equal to in the risers and there is two fitting per risers.

$$\Delta Pf = 0.9 * 16 * 991 * \frac{(0.00065)^2}{2}$$

$$\underline{\underline{\Delta Pf = 0.3014 Pa}}$$

$$\Delta P_{collector} = \Delta P_r + \Delta P_h + \Delta P_f$$

$$\Delta P_{collector} = 4.449 + 2.7155\ 4 + 0.3014$$

$$\underline{\underline{\Delta Pcollector = 7.46058 Pa}}$$

iv) Pressure Drop in the Pipe Lines

Piping lines has pressure drop in transporting the water.

$$\Delta Ph = f * \frac{Lp}{Dp} * \rho * \frac{(Vvaver)^2}{2} --------- Eq(7.20)$$

Where:

L_p is length of the pipe.

Dp is the internal diameter of the pipe.

ρ is the average density of the hot water in the given temperature

$(Vvaver)$=are the average velocity of the fluid flow in the pipe.

$$\Delta Pp = 0.088 * 10 * 991 * \frac{(0.02)^2}{2 * 0.026}$$

$$\underline{\underline{\Delta Pf = 6.6914 Pa}}$$

B) Pressure Drop in the Supply Lines

Supply lines has pressure drop in transporting the water.

$$\Delta Ph = f * \frac{L_S}{Ds} * \rho * \frac{(Vvaver)^2}{2} ------------- Eq(7.21)$$

Where:

L_S is length of the supply pipe.

Ds is the internal diameter of the supply pipe.

ρ is the average density of the hot water in the given temperature

$Vvaver$ is the average velocity of the fluid flow in the supply pipe.

$$\Delta Ps = 0.088 * 10 * 991 * \frac{(0.02)^2}{2 * 0.026}$$

$$\underline{\underline{\Delta Ps = 6.6914 Pa}}$$

C) Pressure Drop in Tube Bend

Tube bend has pressure drop in transporting the water.

$$\Delta \mathrm{Pb} = \mathrm{kf} * \rho * \frac{(Vvaver)^2}{2} \text{ ------------ } Eq(7.22)$$

Where:

kf is Pressure loss factor mostly taken as 0.9.

ρ is the average density of the hot water in the given temperature

$Vvaver$the average velocity of the fluid flow in the supply pipe.

$$\Delta \mathrm{Pb} = 0.9 * 4 * 991 * \frac{(0.002)^2}{2}$$

$$\underline{\underline{\Delta \mathrm{Pf} = 0.71314 Pa}}$$

D) Drop to the Inclination of the Collector

Collector is tilted to south at optimized angle due to this there is some pressure drop

$$\Delta \mathrm{Pi} = \rho\mathrm{gh} \text{ ---------------- } Eq(7.23)$$

Where:

$h\ is\ L \sin\beta$ high of installed collector module

L is the collector length an β the inclination angle.

$$\Delta \mathrm{Pi} = 998 * 9.8 * 0.25$$

$$\Delta \mathrm{Pi} = 2{,}445$$

Therefore:

$$\Delta \mathrm{Pt} = \Delta \mathrm{P_{collector}} + \Delta \mathrm{P_p} + \Delta \mathrm{P_b} + \Delta \mathrm{P_s} + \Delta \mathrm{P_i} \text{ ----- } Eq(7.24)$$

$$\Delta \mathrm{Pt} = \mathbf{7}.46058 + 6.6914 + 0.7135 + 6.691 + 2445$$

$$\underline{\underline{\Delta \mathrm{Pt} = 2.4663 \mathrm{kpa}}}$$

From the total pressure drop

$$Ht = \frac{\Delta Pt}{\rho\ g} \text{ ------------------ } Eq(7.25)$$

$$Ht = \frac{24663}{998 * 9.8} = \mathbf{2.52m}$$

Since the system is designed for middle residential home it will have considerable vertical height 3.25m and the total head will be 5.78m

Note: once determined the total head and flow rate it is easy to select the pump.

7.5 Selection of Electrical Auxiliary Components

7.5.1 Electrical Energy Storage Battery

Since the electrical appliances may not be used in a day time when the radiation is active and the electrical power may be used in the night time. Hence the batteries are essential as a means of power storage to provide smooth and continuous power demand. The battery size and type are most key factors for selection batteries for solar energy. The size of batteries depends on the load and availability parameter. Although battery types of lead-acid, nickel cadmium, nickel hydride, and lithium are well-known in PV power systems, deep cycle lead-acid batteries are the most commonly used batteries. Flooded or valve regulated batteries are commercially available with range of size. Flooded batteries are long lasting and more care sensitive than valve regulated batteries but the valve regulated batteries require less maintenance. For PV systems, the main important condition of batteries is that the batteries must be able to assent repeated deep charging and discharging without being impaired. However, there is appearance similarity with car batteries, car batteries are not designed with repeated deep discharges. Batteries are arranged mainly in parallel but also some in series to full fill the inverter or load voltage of a system. Batteries should be located in an area with moderate temperature. When extreme temperature prevails, batteries must be ventilated effectively. When the irradiation gets low during day or night, the battery should deliver the energy to the load. Moreover, batteries are required in such a system because of the unstable nature of the PV system output. Batteries are categorized by their nominal capacity (qmax), measure by number of ampere hours (Ah) maximum capacity that can be taken out from the battery infixed discharge conditions. The ratio of the charge taken out (Ah) during discharge divided by the amount of charge (Ah) needed to restore the original state of charge is the efficiency of the battery. Therefore, the efficiency depends on the condition of charge and the charging and discharging current. The state of charge (SOC) is the ratio between the present capacity of the battery and the nominal capacity.

$$SOC = \frac{q}{q_{max}} ------------------------ Eq(7.26)$$

SOC can be take values between 0 and 1. If SOC = 1, then the battery is fully charged; and If SOC = 0, then the battery is completely discharged. The number of batteries shall be design to full fill the required service with consideration of bad weather which may last for three days of cloudy and rainy days in which generation of power is less.

Battery Voltage = 12V and Current hours = 250Ah;

$$C = \frac{L * N}{\eta batt * D} ------------------ Eq(7.27)$$

$$B = \frac{C}{Current\ hours * battery\ voltage} ------------- Eq(7.28)$$

Where: L = mean daily energy consumption (kwh/day).

N = Number of days of battery storage (day)

$\eta batt$ =Battery efficiency (-)

D = Depth of discharge (-)

C = Storage Capacity (Wh)

B = Number of barratries

The house appliance and adapters are most often designed for alternating current (AC) while the current generated from PV system is a direct current (DC). And hence an inverter is an electrical device used to convert the direct current DC into alternating current AC electricity so as the power is delivered easily with the house appliance current. The output of the inverter can be single or three phase. Inverters are rated by the total power capacity that ranges from hundred watts to megawatts. From the power required at the load, the type and size inverter should be specified according the design load meant to serve the system. The inverter is characterized based on the power-dependent efficiency, η_{inv} in addition to conversion function of the DC in to AC, maintaining constant AC voltage to the load and the input power with rated efficiency is also main task of the inverter. Hence with specified efficiency of the inverter equation below is given compute respective voltage and current of both sides.

$$\eta inv = \frac{Pout}{P\ in} = \frac{Vac * Iac * \cos(\varphi)}{Vdc * Idc} ---------------------- Eq(7.29)$$

Where: $\cos(\varphi) = is\ power\ factor$

$$Vac = Alternating\ Voltage\ to\ the\ load$$

$$Vdc\ = Voltagerequired\ by\ the\ inverter\ from\ the\ DC$$

$$Idc = current\ required\ by\ the\ inverter\ from\ the\ DC$$

$$Iac\ = Alternatting\ current\ to\ the\ load$$

The voltage and frequency with the use of appropriate transformers, switching, and control circuits shall give smooth conversion process of power. Inverter specification is needed to be selected to fit the system with smooth operation hence the inverter shall be of the following specification.

7.5.2 Charger Controller

A charge controller is a charge regulator or battery regulator which limits the rate of electric current is added to or drawn from a battery and thereby regulates the power from PV module. The controller type could be shunt or series. To prevent over discharge of batteries, the controller should function as low voltage cut off. Selection should be made with correct capacity and required features (ASHRAE, 2004). Usually, the controller is situated after the PV and before the battery that determines operating voltage of the PV. But the battery voltage may not be the optimum PV operating voltage. In order the PV to operate with maximum power point, the controller can optimize the operating voltage of the PV modules without help of the battery voltage. And the power system should include a controller and a control approach, which illustrate the interactions between its components. It is must to use charger controller whenever batteries are employed as a storage medium. The power charging management to battery from the PV system and to the load can be well treated through the controller with suitable maximum and minimum battery voltage values. The following two main operation modes of controllers are widely known: -1. Normal operating condition, where the battery voltage fluctuates between the acceptable maximum and

CHAPTER-EIGHT

8. RESLUT AND DESCUSION

As it is has described in the introduction of chapter six, simulation using Matlab has significant mater on the numerical approach and the pillar mathematical equation are scripted as M- file finally the required graphs' are conspired.

8.1 Hourly Solar Gain on the Inclined Surface

Taking the HDKR model that described in the solar assessment equation Eq(3.21)and the average five-year metrological data for the selected area. The physical parameters of the given system such geographical relationship, geometrical dimension of the collector and each variable are manipulates as input data's and the hourly solar gain on the inclined surface is as show below

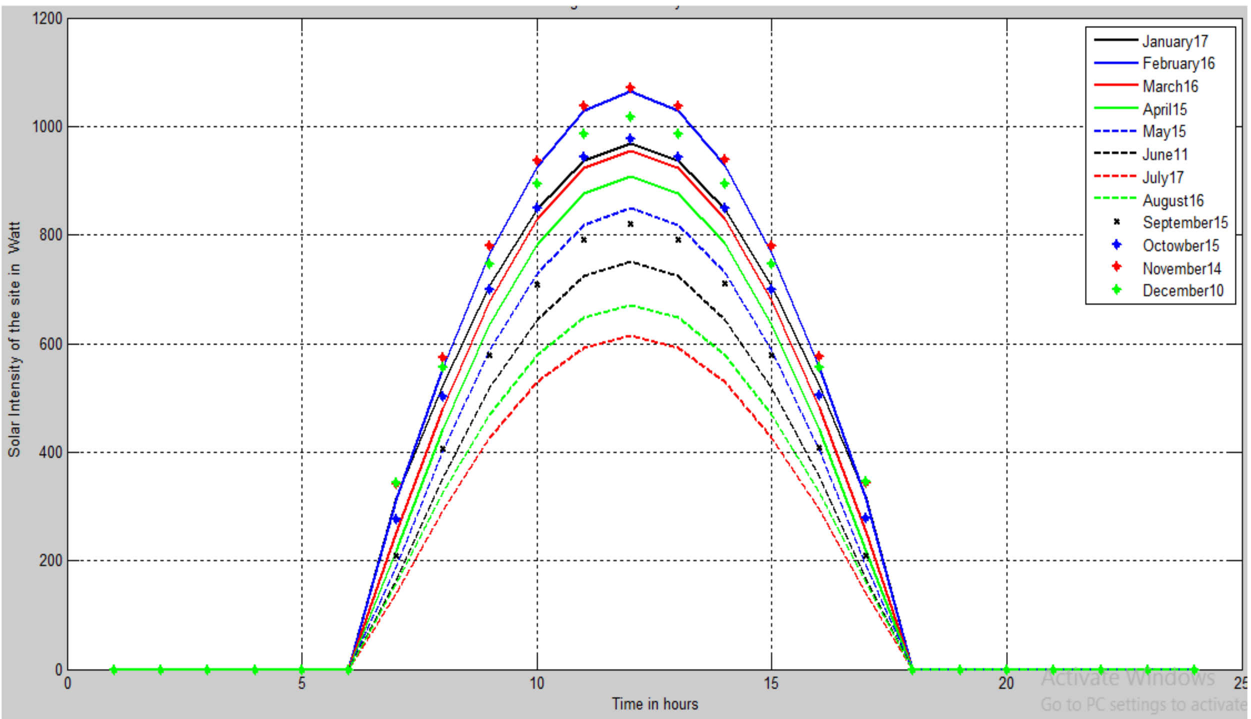

Figure 8.1 Average Hourly Solar Radiation for each Month

Accordingly, the solar radiation in the inclined surface is calculated as average hourly for each month and there is maximum solar radiation in February November, December and October, which is greater than 700 Watt per meter square for 5 hours' time duration. Similarly, the minimum solar radiation is accord in July, August and June which is below 600 Watt and above 400 Watt for 5 hours' time duration.

Table 8-1:.The distribution of Average Hourly Solar Radiation for each Month in Watt/m^2

h o	In1 7	InF1 6	InM1 6	InA 15	InM1 5	InJ 11	InJu1 7	InA 16	InS 15	InN 15	InD1 0	InOc 15
1	315	312	252.6	217	190	165	139.3	158	208	277	344	277.0
2	521	554	481.2	441	402.6	353	292.6	324	407	503	555	503.6
3	705	765	677.7	634.	587.1	517	425.8	468	578	699	746	699.2
4	847	926	828.4	782	729.1	644	528.4	578	709	849	893	849.5
5	936	1028	923.3	876	818.6	723	592.9	647	791	944	986	944.2
6	967	1063	955.8	908	849.2	751	615.1	671	820	976	101	976.6
7	937	1029	923.7	876	818.9	724	593.1	648	792	944	987	944.6
8	848 .	927	829.2	783	729.8	644	528.8	578	710	850	894	850.3
9	706	766	678.7	635	588.0	518	426.5	468	579	700	747	700.3
10	523	556	482.5	443	403.7	354	293.4	325	408	505	557	505.0
11	317	314	254.1	219. 2	191.3	166. 3	140.1	159. 6	209. 7	278. 6	346	278.6

Since estimation of solar radiation is the mainstay and the first objective of this paper it needs high reliability and numerical acceptance. And this result is very closed to the research conducted by Mekelle university on "Assessment of solar radiation on Gibba site'' using experimental method. Based on this solar radiation data base it is expected to achieve the other objectives this thesis is target.

8.2 Hourly Glass Temperature

The glass cover which is part of the system design is considered as advantageous on the performance curve. Even though some solar radiation is reflected by the glass it is better useful by minimizing the convectional and traditional heat loss from PV base bored top side and is uses as preventing the system from considerable physical damage and unnecessary dust. Based on the geometrical properties of the glass described in table (4.1) and energy balance on glass cover in equation (5.6) the hourly temperature distribution on the glass is generated from the simulation.

The glass cover has maximum temperature in November which is 310 ^{0}K and minimum temperature in July.

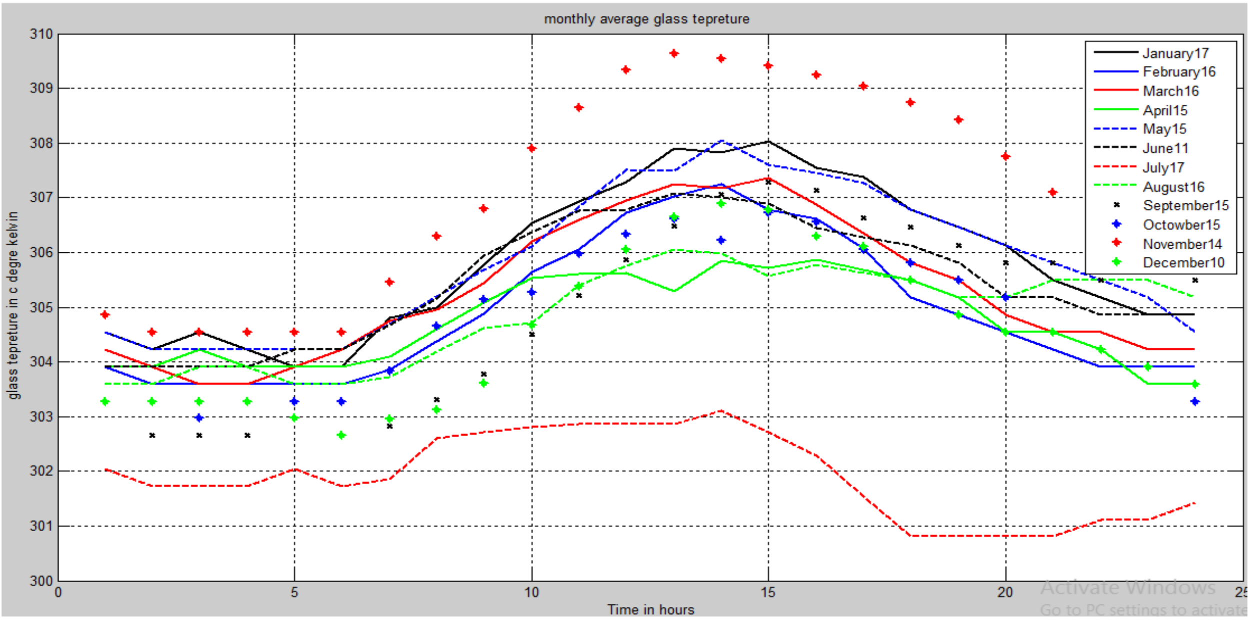

Figure 8.2: Average Hourly Glass Temperature of each Month

8.3 Hourly Temperatures of the PV Layer

Based on the, hourly solar gain above and theoretical design descried in in chapter four in characteristics of PV layer and the equation developed in section mathematical model the MATLAB coding was developed for each mouth of the year. The pv module layer produced the electrical energy and the left heat energy is transfers to heat absorber plat, but some of heat is stored on the pv module which is proportional to the thermal conductive and thickness of the pv module. The energy is distributed as temperature function for pv module as hourly temperature and it is generated from energy balance equation (5.8) and this has the maximum temprature on november 325 0C and the minimum temprature on july 315 0C.of course this temprature highly affected on solar radiation and the mass flow rate and it possible to decreas the temprature the pv by increasing mass flow rate but the outlet temprature of the water will dramatically decreas .and this tempature disstribution is figured as below graph.

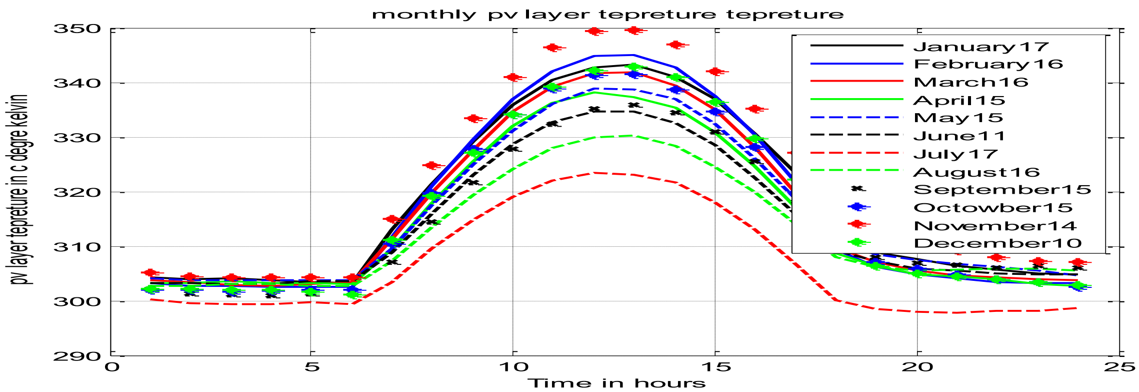

Figure 8.3:Hourly PV Layer Temperature for each Month

8.4 Electrical Output of the Module and its Characteristic Curve

The electrical output of the module is the pillar object of this thesis. In the electrical output section 4.4.1 of this paper it has been showed that the detail electrical proprieties of the photovoltaic module and additional to this, the mathematical formula are devolved to described the significance of the system numerically. In this mat lab manipulation, it considers to illustrate how much the system is affected by the solar radiation and by operation temperature of the module. And this inspiration leads to developing the cooling mechanisms which is called the water based hybrid photovoltaic thermal technology. Finally depending on this result the total size of the PV/T collector will be determined.

a) Effect of Solar Radiation on Electrical Power

Solar radiation intensity has linear and direct relationship with electrical power output as well as the thermal output. With keeping other constant other variable, the effect of solar radiation is shows that, the electrical and thermal output are increased as the radiation increased

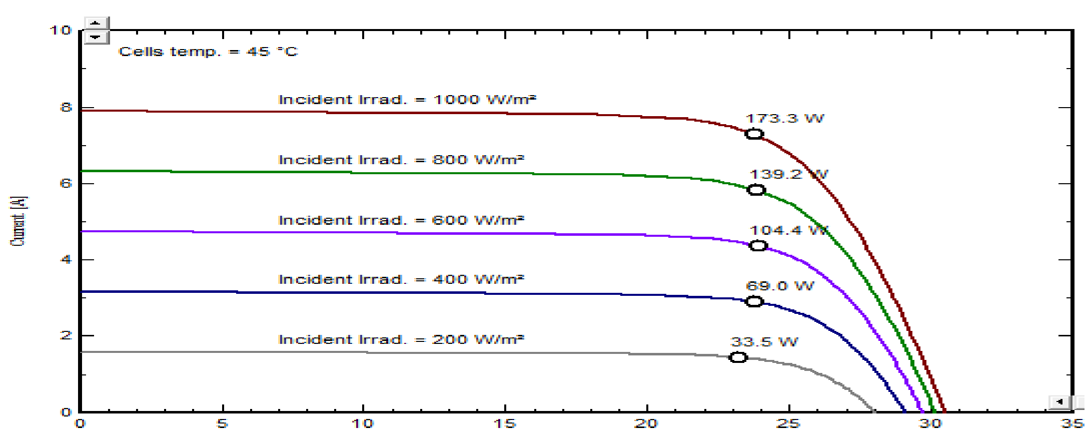

Figure 8.4: The Current –Voltage Curve of the Module

. But the idea keeping other variables constant is not simple task. It needs high research. Because of increasing current do to increment of solar radiation the electric power gain from the system also increase. However, what is keeping in mind that, as the solar radiation increases the operational temperature of the system which is negatively affect the system also increases. For this reason, even there is maximum power at maximum solar radiation the electrical energy efficiency dramatically down at this period. Refer the following P-V and efficiency vs solar radiation graph as function radiation function of temperature.

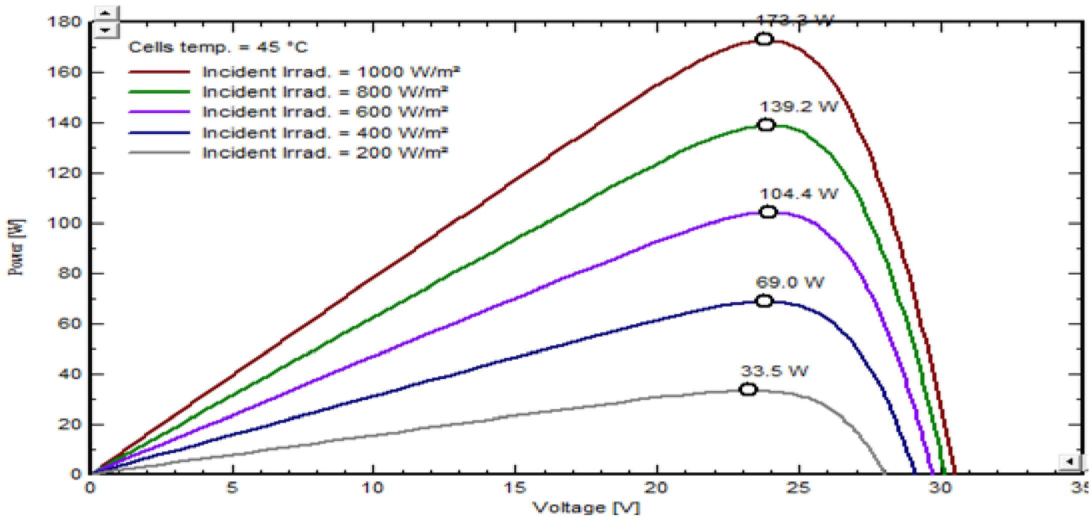

Figure 8.5: The Power -Voltage Curve

In the effect of the operational temperature on the output of electrical energy is increasing as the pv temperature decreasing.

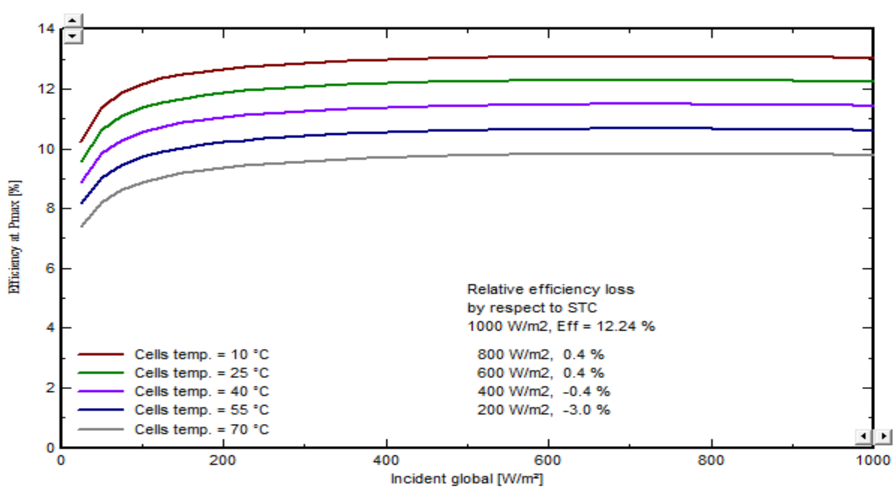

Figure 8.6:The Effect of Operational Temperature on Electrical Output

To determine the effective solar hour and for which maximum power generation hourly power generation in each month is needed and this deploy as follow.

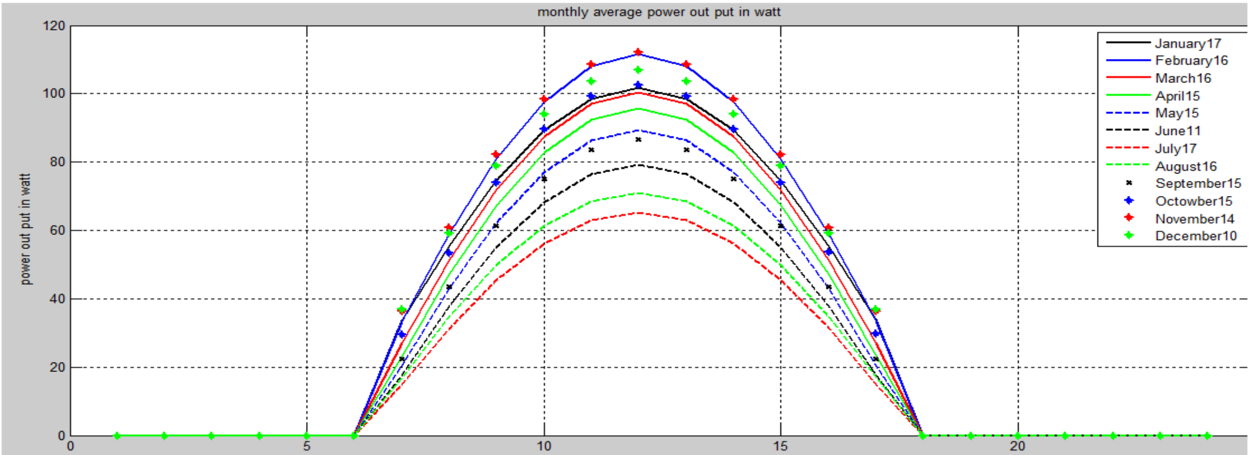

Figure 8.7 Hourly Electric Power Generation for each Month

From the above two power curve someone the first power –voltage curve is slightly less from the second hourly power curve this indicates that the first curve is properly show the internal resistance of the electrical circuit. For determine total area of the collector it important to know the amount of hourly average electric production of the system for each half months through the year. And this is calculated table below. According the metrological data of the site taken, it is ignored the electric production in the 12[th] hour.

Table 8-2:Average Hourly Electric Production for each Month in watt/m^2

Hour	Epl J17	Epl F16	Epl M16	Epl A15	Epl M15	Epl J11	EplJ u17	Epl A16	Epl S15	Epl O15	Epl N14	Epl D10
1	33.6	33.3	27.9	23.3	20.3	17.7	14.9	17.	22.3	29.6	36.3	36.8
2	55.8	58.9	51.1	47.5	42.8	37.6	31.9	34.6	43.4	53.5	60.6	59.0
3	74.6	80.8	71.7	67.2	62.2	54.9	45.4	49.7	61.4	73.9	82.3	78.9
4	89.2	97.5	87.3	82.6	77.0	68.1	56.2	61.3	75.0	89.5	98.1	94.1
5	98.4	107.	97.1	92.3	86.2	76.4	62.9	68.5	83.6	99.3	108.	103.
6	101.	111.	100.	95.6	89.4	79.2	65.3	71.0	86.5	102.	112.	106.
7	98.4	107.	97.1	92.4	86.2	76.4	63.0	68.5	83.5	99.3	108.	103.
8	89.2	97.5	87.3	82.7	76.9	68.1	56.2	61.3	75.1	89.6	98.4	94.1
9	74.7	80.8	71.7	67.3	62.2	54.9	45.4	49.8	61.3	74.0	82.1	78.8
10	55.4	58.9	51.2	47.1	42.9	37.7	31.4	34.7	43.4	53.5	60.8	59.0

11	33.8	33.5	27.1	23.4	20.4	17.7	15.0	17.0	22.3	29.7	36.5	36.9
Average	**77.0**	**79.0**	**69.9**	**65.5**	**60.6**	**53.5**	**44.3**	**48.5**	**59.8**	**72.2**	**80.4**	**77.4**
Pr/d m^2	**847**	**869**	**769**	**721**	**667**	**589**	**487**	**534**	**658**	**794**	**885**	**851**

According to this result it showed, the minimum electric production in the July which is due to low solar radiation of the given site. Based on electric energy demand assessment in chapter three, the PV/T collector area will be determined from this month which lowest electric production of the year.

For more feasible production the electric generation it is logical taking the solar hour is less than the above tabulated date. According to the duration of solar hour equation the selected site has eight hours and it takes as effective and productive time. Considering the annually average production of electric energy it possible to gain 632.2 watt /m^2 in the effective time. And only four-meter square is enough for satisfying the electric energy demand.

8.5 Electrical Efficiency of the System

The Electrical efficiency of the system was defined and determined in the section of performance evaluation in 4.4.3.1. This mathematical determined is simulate to graphical illustration as shown below.

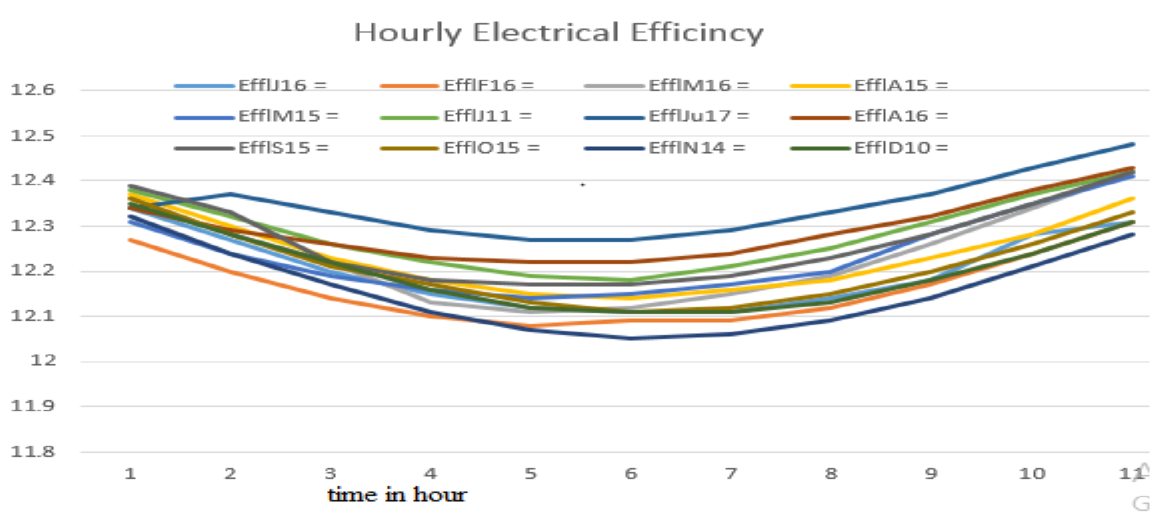

Figure 8.8 Electrical Efficiency of the System

8.6 Output of the Thermal Part of the Module

8.6.1 Heat Stored on the Observer plate

The heat absorber plate is the tool for extracting the excess heat in the PV layer which the transfer to work fluid. As it is briefly explained in section 4.4.2 the direction of heat flow only to norm of the heat observer plate. Based on the mathematical equation from energy balance of the system the temperature distribution on the sheet absorber is gained as figure below. The accumulated heat in the observer plate greater than 400 Watt for the period of fife hour through the year except July and August. This heat is transfer to water which is circulated in the coper pipe with help of fin that is bonded by welding,

The temperature distribution of the heat observer is maximum at November which has above 60^0C and minimum 35^0C.since the heat observer has 0.95 observability it has the ability to maintain its temperature even the solar radiation is decrease.

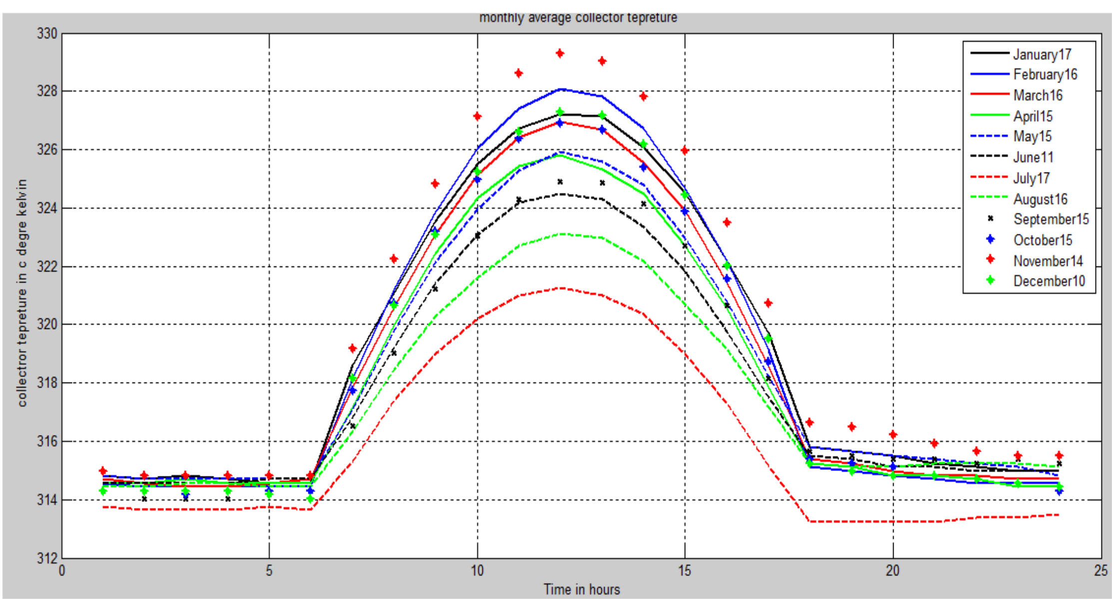

Figure 8.9:Temperature distribution in heat observer plate

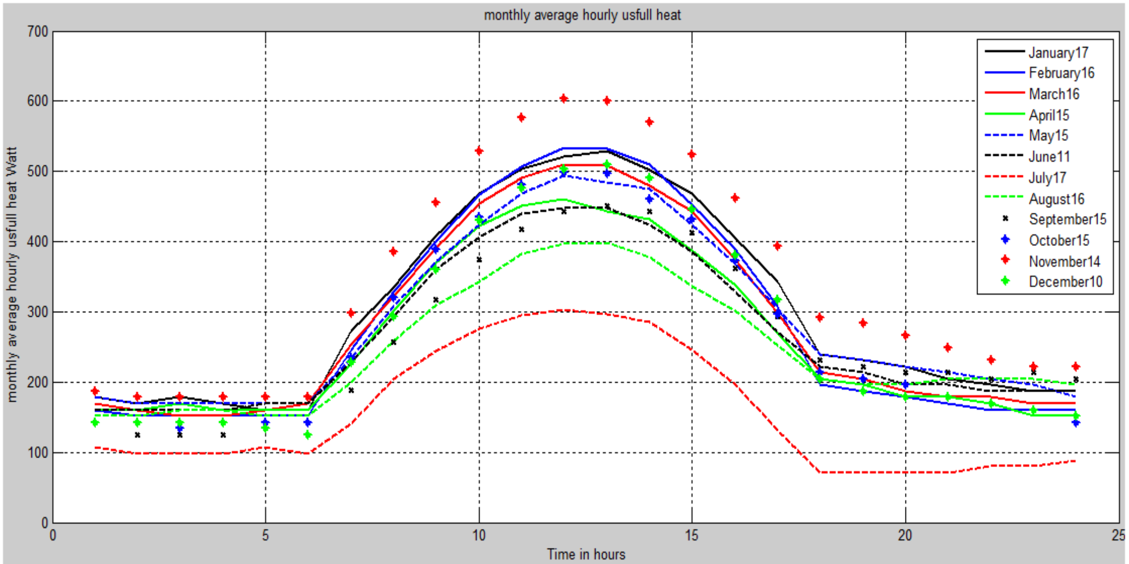

Figure 8.10 :Monthly Average Hourly Heat Gain in observer plate.

Table 6.3: Monthly Average Hourly Heat Gain in observer plate.

h/r	QuJ 17	QuF 16	QuM 16	QuA 15	QuM 15	QuJ 15	QuJu 17	QuA 16	QuS 15	QuO 15	QuN 14	QuD 10
1	272.7	245.6	253.8	225.9	235	227	140	258.	187	234.8	298.5	228
2	335.2	327.7	322.8	302.2	307	293	204	310	256	320.8	385.2	293
3	407	400	390.9	369.2	372	359	244.	343	317	388.8	455.6	360
4	467	666.4	453.7	422.1	423	406	276	381	374	434.6	529.2	431
5	503.2	506.3	491.0	451.2	423	439	295	397	417	480.5	576.0	476
6	521.1	533.8	509.4	461.0	467	447	302	399	442	498.8	602.9	503
7	528.9	509.2	508.2	442.8	493	447	295	378	451	497.5	601.0	510
8	502.3	451.9	479.5	431.6	484	423	285	336	443	460.5	571.0	490
9	467.8	388.6	442.5	386.7	474	385	245	302	412	432.0	532	446
10	404	307	375	337	423	328	195	215	367	373	462	380
11	342	195	298	270.	368	271	131	156	293	296.65	393	317
12	239	187	213.6	204	239	22	71	143	231	213	292	204

Since the useful heat is observer plate is minus of electrical energy and losses from the energy of solar radiation, it is minimum in the July and august and maximum in the October, November and December. Based on this energy available the amount hot water generated will estimated under consideration the collector efficacy.

8.6.2 Fin Temperature

The fundamental use of fin has discussed in the section 5.4.2 and has been that the detail mechanism of the heat flow toward the low temperature. This fin is made up coper material for high transmittance of the heat along the its longitudinal section. The temperature distribution on this fin is maximum at central distance of the fin at and at the end of time step the conduction.

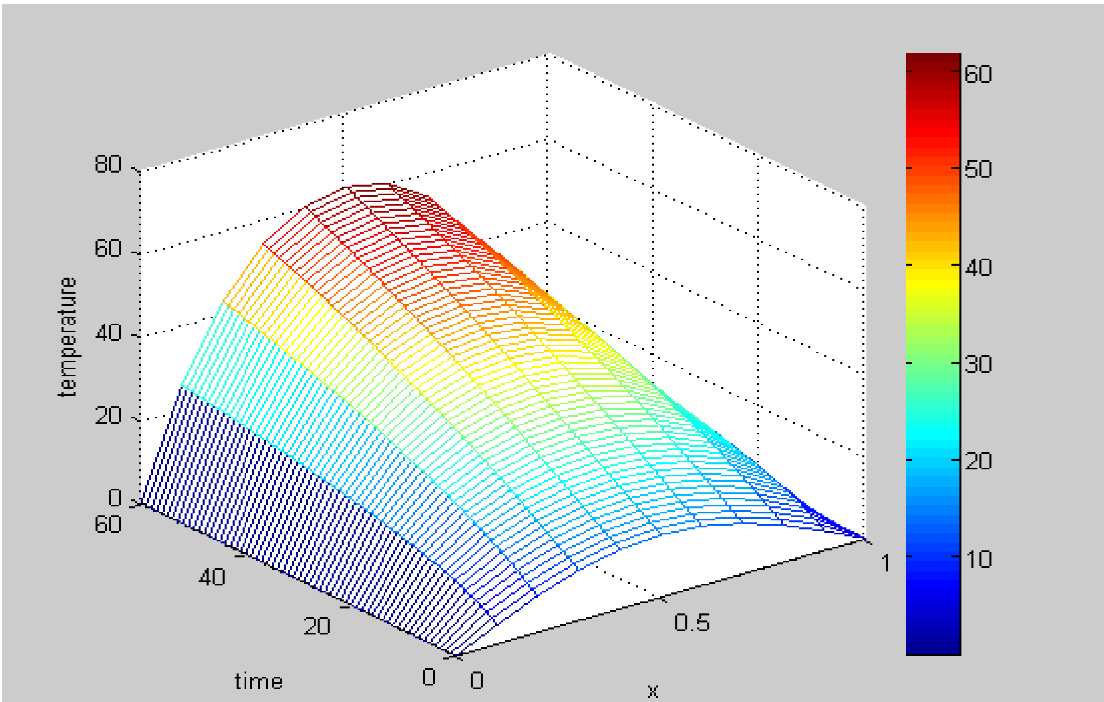

Figure 8.11:Figure temperature distribution on the coper fin

The temperature of the fin in the two edge are absolute zero because of the insulate boundary in ideal analysis but in actuality it different from this value.

8.6.3 Hourly Outlet Water Temperature

The outlet temperature of the water highly dependent of rate mass flow as the other parameter are remain constant. In the case of this manipulation it is used the minimum mass flow rate 0.002 kg/s/m^2 for minimum solar radiation and used mass flow 0.02 kg/s/m^2 for maximum solar radiation in order maintain the out water temperature as soon as the hot water demand is needed at 45^{0}C. Taking the minimum condition for better factor of safety around 250 litters of hot water can be generated at the average temperature (43^{0}C-50^{0}C) for ten months. Look the Matlab result below.

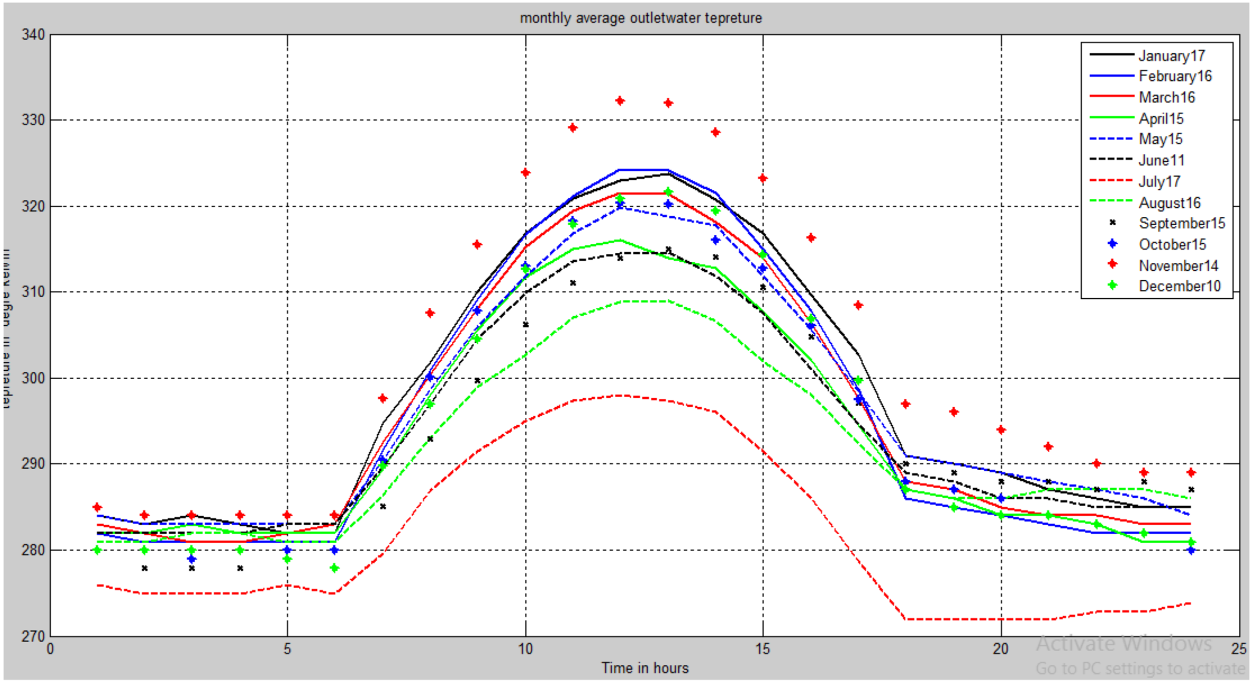

Figure 8.12: Hourly Outlet Water Temperature for each Month

For comparison of the hot water consumption and the hot water production at each hour must be determined using the useful heat gain and the desired temperature. This is calculated from the form the equation 5.13. In general, except in July in the reset month it possible to produce more than 250 liters per day at the temperature of 45 °C, at lowest minimum assumption solar radiation.

8.6.4 Thermal Efficiency of the System

This is the technical parameter for evaluating the thermal output verses the accumulated heat in the solar collector and it uses for determine thermal efficiency of the system. The mathematical description has already mentioned in the section 5.6. for simplification it takes the four sample months July, March, September, and October and they produce in the range of 45%-65% thermal efficiency in the effective solar hour period. Look the figure below.

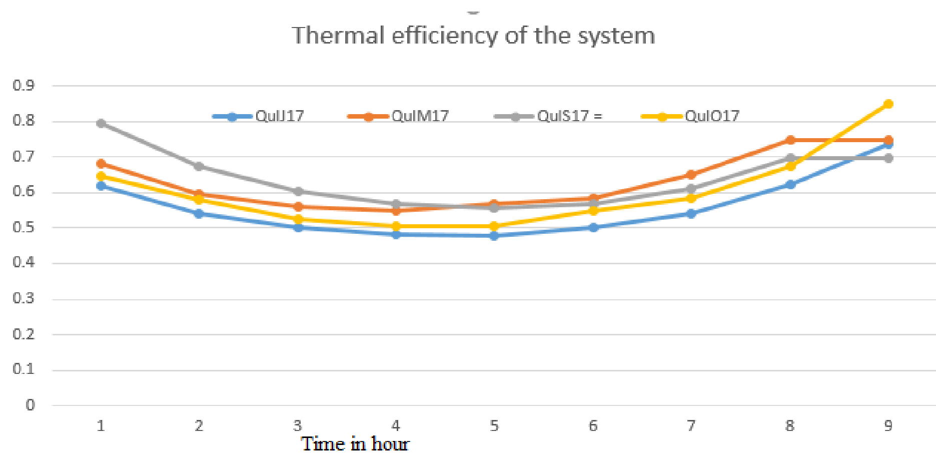

Figure 8.13:Thermal efficiency of the system

In running of thermal efficiency of the system the result indicates that the thermal efficiency decreases as solar hour goes to the midday. This is because that the thermal output of the system which hot water temperature is fixed at optimized point by varying the mass flow rate the water to maintain the operation temperature of the system for increasing of generation of electrical energy.

CHAPTER NINE

9. ECONOMIC AND ENVIRONMENTAL EVALUATION

9.1 Introduction

The design of water based photovoltaic thermal has been showed through the chapters listed above and has try to indicate the advantage of this technology using technical evaluation. But all consumers or users may not understand this terminology easily and it important to introduce other method of evaluation which has the ability illustrates the given system in terms of economic and environmental feasibility measures. In fact, economical figures have a central role in any consumer behavior. Means that Economical Evaluation is preferable on the study of individuals, groups, or organizations and the processes they use to select, secure, and dispose of products, services, experiences, or ideas to satisfy needs and the impacts that these processes have on the consumer and society. In terms of economic measures of the PV/T, Tripanagnostopoulos et al, suggested the life cycle cost assessment method which takes into account the capital cost of system installation and associated operational and maintenance cost over the system's life cycle. [25]

9.2 Economical Evaluation

In this paper economical evaluation (cost benefit analysis) process estimates the benefits and costs of an investment for two reasons:

- To determine if the project is viable; if it is a good investment.
- To compare PV/T with other competing projects, such as PV, Diesel generator.

Thus in case for this paper it will try to screen the performance of the system both in economic and environmental point of view.

9.2.1 Life-Cycle Economic Analysis

a) Capital Cost of the PV/T System

To install a new solar system, it might be possible to receive grants through the government's renewable policy, such as the Renewable Energy Incentive (RHI) which is intended to encourage the uptake of renewable technologies within households, communities and businesses through the provision of financial incentives. And this helps that nobody thinks opportunity cost over Ecological system, hence it is assumed the system is free from initial investment interest and tax.

The capital cost of the PV/T system was estimated by adding together the individual prices of all the system components and taking into account appropriate commercial cost. Table 8-1 provides a list of cost breakdowns and indicates that the initial cost of such a system is the cost details of the different system components are presented.

Table 9-1: Total Cost Break Down per Collector

No	System component	Cost in ETB
1	Glass cover low iron	250.00
2	PV –laminated	7,700.00
3	Al –sheet	320.00
4	Selected surface absorber with copper tub	1,540.00
5	Collector house and support	1,300.00
6	Inverter	1000.00
7	Differential controller	700.00
8	Hot water storage tank	4000.00
9	Pump and pipe work	1,500.00
10	Shortage battery	3,000.00
11	Installation cost	1% of the capital cost
12	Maintenance cost	1.5% total cost
	Ground total per m^2 PV/T	21,290.00
	Ground total for 4 m^2 of PV/T	84,960.00

b) Life Cycle Cost of the System

Life cycle –cost includes investment capital and present worth of operating cost during the useful life of the plant. The operation cost is mainly focused estimated from the pumping and maintenance cost. The life cycle –cost may be determining from the capital cost, maintenance cost, interest of the give O&M cost over the life span of the system.

$$LCC = CI + CM\frac{1}{i}\left(1 - \frac{1}{(1+i)^n}\right) ------------------------- Eq(8.1)$$

Where: LCC = is the life cycle cost in birr.

CI = is the investment cost

CM= is the annual maintenance and pumping cost

n and i = are the life time year and the interest respectively

Taking the average life time 25 year of the give system and 10% the interest with maintenance cost and pumping cost 1.5 % of the initial capital the life cycle –cycle will be as follows.

$$LCC = 80,000 + \frac{4}{100} * 80,000 * \frac{1}{0.1}(1 - \left(\frac{1}{(1.1)^n}\right))$$

$$\underline{\underline{109{,}154.26\ birr}}$$

To determining the unit price (Pe), the life cost cycle has to be equal to cycle saving

Annual energy saving $Es = faQa$

When fa is the solar fraction which is taken as 0.85 in most of the off- grid system and Qa is the annual energy gain sum of electrical and thermal from the system. Where it assumed the total electrical energy per day is 5 kWh from the energy demand assessment and annually becomes 1825 Kwh and the thermal load will be calculated from the totally hot water demand per day which is function of mass flow of the water and temperature difference input and output temperature of the hot water. This is annually yielded 3193.75 when it is changed to equivalent electrical energy and the total consumed annually energy is the sum both energy feastings.

$$Q_a = E_c + Th_c ---------------------Eq(8.1)$$

$$\underline{\underline{Qa = 5018.75kWh}}$$

c) Life Cycle Saving

Life cycle saving of solar system is the energy cost saved due to replacing of fuel by PV/T.

$$LCS = PefaQa\frac{1+ie}{i-ie}\left(1-\left(\frac{1+ie}{(1+i)}\right)^n\right) ----------- Eq(8.2)$$

Where Pe is the unit energy cost, e the energy inflation through the life span of the PV/T and takes as 8% which is less than the interest the bank loan. To determining the unit price, we equate the above two equation

$$CI + CM\frac{1}{i}\left(1-\frac{1}{(1+i)^n}\right) = PefaQa\frac{1+ie}{i-ie}\left(1-\left(\frac{1+ie}{(1+i)}\right)^n\right) --- Eq(8.3)$$

$$Pe = \frac{CI + CM\frac{1}{i}\left(1-\frac{1}{(1+i)^n}\right)}{faQa\frac{1+ie}{i-ie}\left(1-\left(\frac{1+ie}{(1+i)}\right)^n\right)} -------------Eq(8.4)$$

$$Pe = \frac{109{,}154.26\ birr}{0.9 * 5018.750\frac{1+0.08}{0.1-0.08}\left(1-\left(\frac{1+0.08}{(1+0.1)}\right)^{25}\right)kWh} ----Eq(8.5)$$

$$Pe = 1.516\frac{birr}{kWh}$$

9.3 Comparing the PV/T with Diesel Fuel Cost

Comparing the PV/T with different energy alternatives such as diesel generators has a great impact on its market character because consumer who live under economic standard select the direct cost as the first parameter. Based on this thesis it compared with diesel generators since it the most commercial on off-grid energy supply systems. To do this calculating the unit energy cost for diesel generators must be estimated. Taking the fuel cost 20 ETB per litter (0.8kg) within 25 years and taking heating value of the fuel 34,513.57 kJ/li.

$$P_{ed} = \frac{20\ ETB}{34.513.57kJ}$$

$$\underline{5.80 * 10^{-4} ETB/kWh = 2.0 * ETB/kwh}$$

For the 80% generators the unit energy cost will be

$$\underline{2.5 * ETB/kwh}$$

The comparison shows that unit energy for diesel generators cost is greater for Pv/t without considering the environmental effect and maintenance cost.

9.4 Payback period of the PV/T

The time needed for the cumulative fuel savings to equal the total initial investment, that is, how long it takes to get an investment back by savings in fuel. The common way to calculate this payback time is without discounting the fuel savings. [7]

$$LCCS = Cff_a Q_a \frac{1+ie}{i-ie}\left(1-\left(\frac{1+i_e}{(1+i)}\right)^n\right) --- \quad Eq(8.2)$$

$$LCCS = Cn \quad at \ n = N_p$$

$$Np = ln\left(1 + \mathrm{CI}\left(\frac{i_e - i}{(1+ie)}\right)Np\right) ------ \quad Eq(8.2)$$

$$Np = \ln\left(1 + \frac{\mathrm{CI}\left(\frac{i_e - i}{(1+ie)}\right)}{Cff_a Qa}\right) * \frac{1}{\ln[\frac{1+ie}{1+i}]} ------ \quad Eq(8.2)$$

$$Np = \ln\left(1 + \frac{84{,}000\left(\frac{0.08-0.1}{(1+0.08)}\right)}{2.5 * .75 *}\right) * \frac{1}{\ln[\frac{1+0.08}{1+.1}]} -- \quad Eq(8.2)$$

$$Np = 11 \text{ years} --------- \quad Eq(8.2)$$

Where:

LCS is the life cycle saving of a solar water heating system [kWh]

LCCS is the life cycle saving of fuel cost [Birr].

C_f is the unit cost of fuel for the first year of analysis [Birr / kWh].

f_a is annual fraction of load supplied by solar energy.

Q_a the annual heating load [kWh].

CI is the initial investment cost, [Birr]

i is the annual market discount rate.

ie is the annual market rate of fuel escalation, and

n is the years of economic analysis.

CHAPTER-TEN

10 CONCLUSION AND RECOMMENDATION

Reference

1. UN Climate Change Conference, <en.wikipedia.org/wiki/Copenhagen Climate Summit, [1/10/2010].
2. Miles RW, Hynes KM, Forbes I. Progress in Crystal Growth and Characterization of Materials 2005;
3. X. Zhao, X. Zhang, S. B. Riffat, X Su, Theoretical investigation of a novel PV/e roof module for heat pump operation, Energy Conversion and Management 2011; 52: 603-614
4. Kalogirou S. Solar energy engineering: processes and systems; London: Elsevier; 2009.
   Duffie J. A., Beckman W. A. Solar Engineering of Thermal Processes, 2^{nd} Edition; New York: John Wiley & Sons; 1991.
5. [American Society of Testing and Materials (2006)].

7 Duffie J. A., Beckman W. A. Solar Engineering of Thermal Processes, 2^{nd} Edition; New York: John Wiley & Sons; 1991.

8 H.A. Zondag, et. The yield of different combined PV–thermal collector designs, Solar Energy 74 (3) (2003) 253–269.

9 Alferov ZI, Andreev VM, Kagan MB, VG. Physics Semiconductors 1971; 40:2047

10 H.A. Zondag, et. The yield of different combined PV–thermal collector designs, Solar Energy 74 (3) (2003) 253–269.

11 Y. Tripanagnostopoulos, et. Yianoulis, Hybrid photovoltaic/thermal solar systems, Solar Energy 72 (3) (2002) 217–234.

12 Chow TA review on Photovoltaic/Thermal Hybrid Solar Technology. Applied Energy (2010) vol (87), pp. 365-379

13 T.T. Chow, ‘Performance Analysis of Photovoltaic–Thermal Collector by Explicit Dynamic Model’, Solar Energy, Vol. 75, N°2, pp. 143 – 152, 2003.

14 H.C. Hottel, A. Willier, Evaluation of flat-plate solar collector performance Transactions of the Conference on the Use of Solar Energy, vol. 2, 1958

15

16

17 Tyagi, V.V. S.C. Kaushik and S.K. Tyagi, 2012, Advancement in solar photovoltaic/thermal (PV/T) hybrid collector technology. Renewable Sustainable Energy Review, 16: 1383-98.

18 Chow, T.T., 2003. Performance analysis of photovoltaic-thermal collector by explicit dynamic model. Solar Energy, 75: 143-52.

19

20 Tripanagnostopoulos Y (2012) Photovoltaic solar collectors. Comprehensive Renewable Energy, vol (3) pp. 255-300

21

22 Huang, B., T. Lin, W. Hung and F. Sun, 2001Performance evaluation of solar photovoltaic/thermal systems. Solar Energy, 70: 443-8.